Small Cells 2017

MOBILE EXPERTS

Abtract:

This report provides comprehesive analysis of trends in Small Cell development, including 2G, 3G, 4G, and 5G small cells and RRH units, as well as integration of LTE and Wi-Fi in unlicensed bands for added capacity.

This market study includes complete forecasts of residential, enterprise, and carrier deployment for small cells, RRH units, and DRS variations. Shipment, revenue, pricing, and market share data are included.

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April 2017

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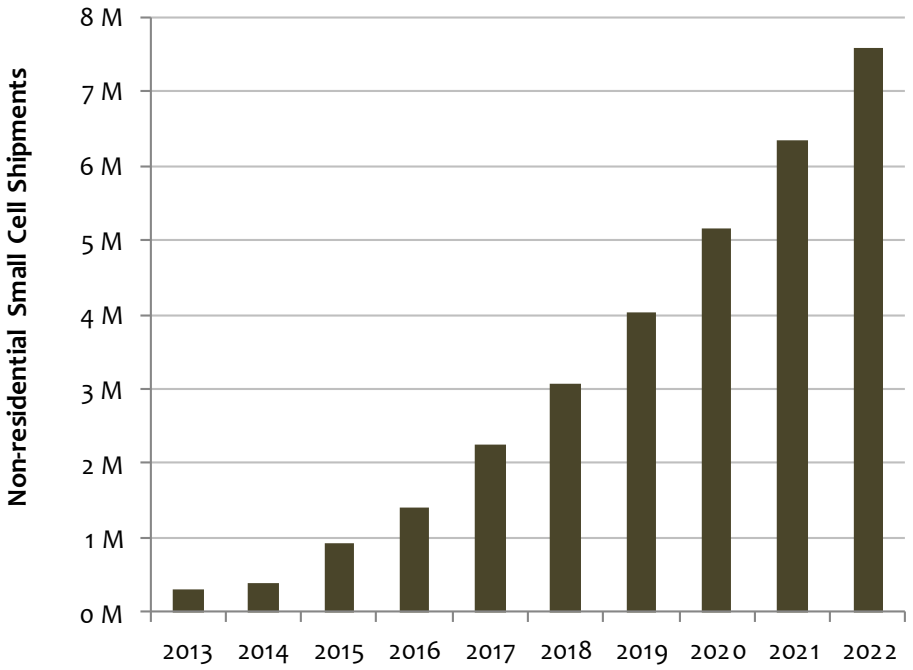
1 EXECUTIVE SUMMARY

The small cell market continues to grow steadily as small cells are becoming an essential part of carrier infrastructure. Although our forecast updates throughout 2016 ratcheted down--as a couple of key programs in China and 'direct-to-enterprise' channel did not materialize as we had anticipated--we saw stronger growth elsewhere. More importantly, for ecosystem suppliers, the volume was driven by carrier indoor and outdoor applications. The residential market is flat, but the non-residential market has started on a path of impressive growth. Excluding residential femtocells, we expect the carrier and enterprise segments to grow at over 30% CAGR from 2016 to 2022.



Source: Mobile Experts

Chart 1: Non-Residential Small Cell Growth Forecast

Market trends point to a continued upward trajectory during 2017. Carriers with broad LTE coverage are leveraging small cells for indoor and outdoor applications, to increase capacity and expand mobile coverage in high-value locations within macro coverage areas. During 2017 and beyond, we expect the non-residential small cell market to accelerate with the following trends providing 'tailwind' momentum:

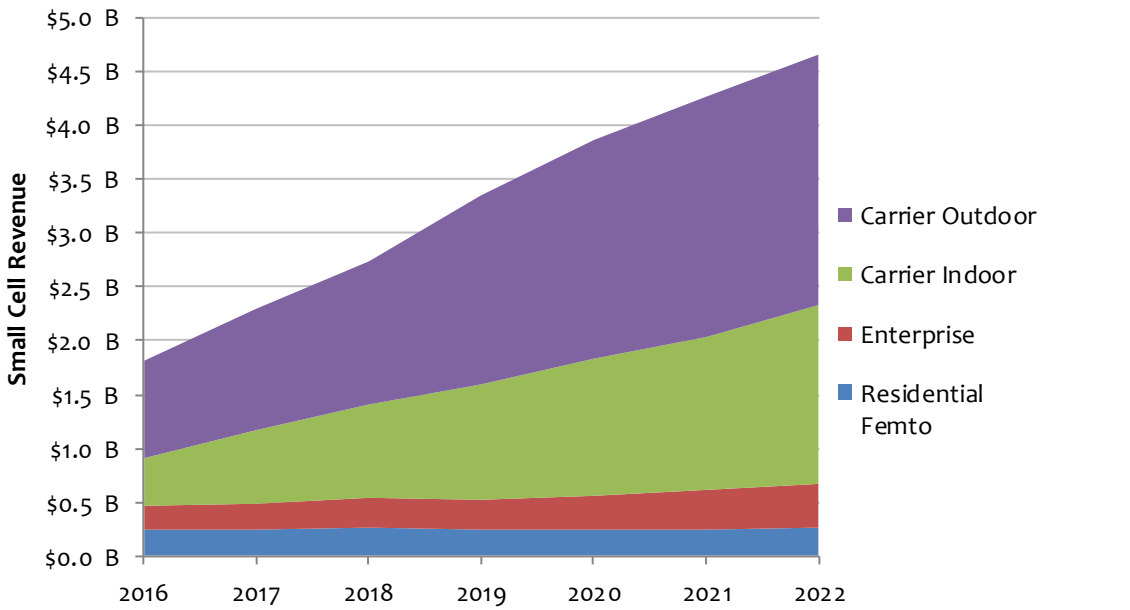
- Increasing carrier small cell deployments in China and APAC, including the second phase buildout of Reliance Jio's LTE network;
- US carriers' steady buildout of small cell networks. While the US operators will target both outdoor and indoor small cell deployments, we expect Verizon and T-Mobile US to be more focused on indoor deployments at key enterprise venues,

while Sprint to focus heavily on outdoor deployments to expand coverage and capacity with abundant 2.5GHz spectrum holdings;
- Competitive market conditions all around the world (e.g., 'unlimited' data plans in the USA, Jio's aggressive market entry in India, etc.) are forcing carriers to continue to expand their network capacity and coverage, and small cell deployments are viewed as a cost-effective means to address targeted market demands within macro coverage areas;
- Fixed mobile convergence trends and unlicensed/shared spectrum technologies may enable new players to enter the market through small cell deployments at key venues and on top of fixed network footprint.

Technology and spectrum choices for small cells are expanding. Small cell OEM suppliers are introducing innovative products that address specific requirements for target market segments, including flexible fronthaul/backhaul options and expanding frequency band support across licensed, unlicensed and shared spectrum bands. Low power RRH units have proven to be an essential part of the HetNet architecture. Distributed Radio Systems (DRS) like Huawei's LampSite have been hugely popular with carrier indoor deployments, especially in China and APAC regions. The CPRI architecture is expected to shift to split-baseband architecture over time to maintain more reasonable fronthaul bandwidth requirements. Carrier aggregation, on both licensed and unlicensed bands, will play an integral role in driving higher capacity at lower cost.

While 'direct-to-enterprise' market momentum stalled in 2016, we are optimistic that new business models will eventually come to fruition. Carriers need trusted third-party partners to address the pent-up enterprise demand for in-building wireless at scale. As small cells become an integral part of mobile infrastructure, new business models centered on outsourcing for carriers and enterprises by neutral host providers or key enterprise channel partners will eventually emerge. To alleviate structural inefficiency around fragmented deployments in various markets, existing infrastructure players such as tower companies and new emerging players will start to offer bundled services around backhaul, site lease, and maintenance to offer all-in-one 'small cells as a service' to ease and accelerate adoption.

Overall, the small cell market is evolving rapidly. Technology choices including FDD/TD-LTE, LTE-U/LAA, LWA, CBRS, and even Carrier Wi-Fi are available for carriers and enterprises to address skyrocketing mobile data growth. While major mobile infrastructure suppliers, including Ericsson, Huawei, and Nokia, take larger shares of the carrier outdoor segment through 'macro parity' small cells, which take advantage of their macro 'footprints', smaller companies such as Spidercloud and Airspan are finding success in enterprise and indoor segments at several Tier 1 operator accounts. By 2022, we expect Small Cell revenue to triple, to reach over $4.5B.



Source: Mobile Experts

Chart 2: Small Cell Revenue Forecast, 2016-2022

As operators evolve towards hyper-dense networks with 5G services, small cells will be an integral part of mobile networks, and small cell solutions will constitute an increasing share of capital expenditure. Regulatory and business challenges for accelerating the outdoor and enterprise segments remain. However, key drivers and guideposts for small cell investments (i.e., increasing mobile demand, competitive intensity, technology and spectrum abundance, denser RAN towards 5G, etc.) are trending up. We remain optimistic that the small cell market will continue its upward trajectory – whether that growth will mirror a 'hockey stick' or a 'steady ramp' remains to be seen.

2 PREFACE: FORECAST MODEL FRAMEWORK CHANGE

In this year's update, we have made several changes to our forecast model in order to streamline different small cell categories that we have tracked historically into commonly acknowledged product categories based on business segments. In the process, we hope to simplify our model so that our clients can quickly find relevant information and correlate to commonly accepted categorization of small cells.

Here are the major changes to our model framework:

- The small cell categorization has been reduced to *Residential Femtocells*, *Enterprise*, *Carrier Indoor*, and *Carrier Outdoor.* These represent generally accepted categorization of small cells in the industry, encompassing different product features and business segments that the small cell products address.
- The traditional *Microcell* category associated with older 2G/3G RNC or BSC based architecture has been absorbed into the *Carrier Outdoor* segment.
- Traditional *Outdoor/Indoor Picocell* categories have been absorbed into the *Carrier Outdoor* and *Carrier Indoor* segments.
- *Hi Power Outdoor* category has been included in the *Carrier Outdoor* segment. It should be noted that the new model tracks high power (i.e., *Hi Power Outdoor*) units separately within the *Carrier Outdoor* segment.
- *Remote Radio Head (RRH)* units are tracked within each of the new categories as a part of the new segmentation by fronthaul/backhaul architecture.
- This new "fronthaul/backhaul" segmentation tracking is broken into:
    - *CPRI RRH*: CPRI based fronthaul or backhaul found in today's RRHs;
    - *Split Baseband RRH*: proprietary demarcation of baseband functions across RRH and baseband unit to reduce fronthaul/backhaul bandwidth requirements;
    - *Integrated*: integrated baseband and radio unit found in most integrated small cells.
- Digital radio systems (DRS) like Huawei's LampSite and Ericsson Radio Dot radio units were not counted individually in our previous model. Individual radio units are now counted in the new model. Previously we had counted the number of DRS hubs as part of RRH shipments.
- Because of accounting individual DRS radio units, the *Carrier Indoor* and *Carrier Outdoor* units will appear much larger than our previous model. However, it should be noted that the revenue contribution should be similar based on our average selling price assumptions.

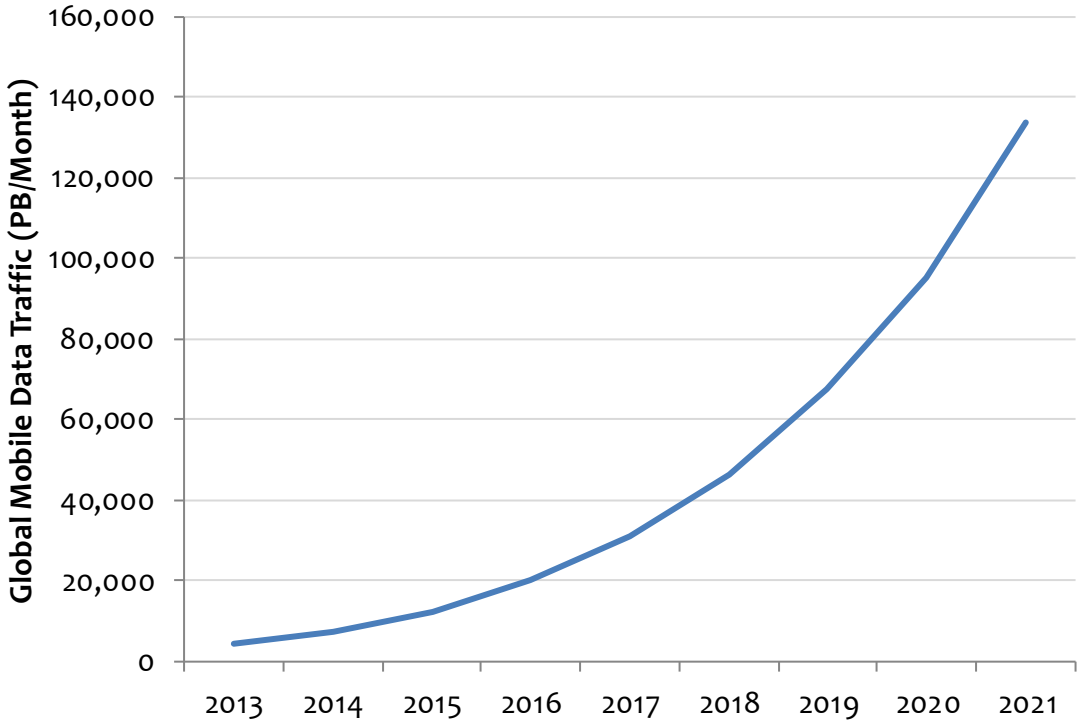
With these changes, we hope that you find the updated model useful. (If not, please let us know. We are always listening.)

3 MARKET DRIVERS

Small cells are becoming an essential element in the operator 'toolbox' to primarily augment network capacity, but also to expand mobile coverage indoors and outdoors in both dense urban and rural areas. While the underlying macro trend of increasing mobile data traffic fundamentally drives the demand for small cells, competitive market conditions and network evolution towards 5G are also accelerating investments in small cell deployments.

Mobile Data Demand

The growing demand for mobile data continues at a strong pace, with 60% higher data traffic demand every year. The sheer weight of mobile traffic is a burden on the macro network, but it's important to note that a great deal of the data growth is taking place in very specific locations. Data demand is becoming more "spotty", meaning that key locations such as stadiums and transportation hubs experience very high data traffic density, while the data demand on an average street does not see the same growth.



Source: Mobile Experts, Cisco, Ericsson, Mobidia

Chart 3: Global Mobile Data Traffic Growth

In fact, total traffic demand itself does not directly drive small cell deployment. The *density* of mobile traffic, not the sheer volume of traffic, is the driving force behind most small cell adoption in urban areas. As an example, if mobile data traffic were evenly distributed across the countries of Japan or South Korea, there would be no need for small cells.

For cultural, demographic, and economic reasons, the peak density in key neighborhoods of Seoul and Tokyo runs about 12-15 times more data per square kilometer than the peak mobile data demand in an average worldwide city. This factor has increased steadily over the past five years, showing that data demand is now more "spotty" than ever.

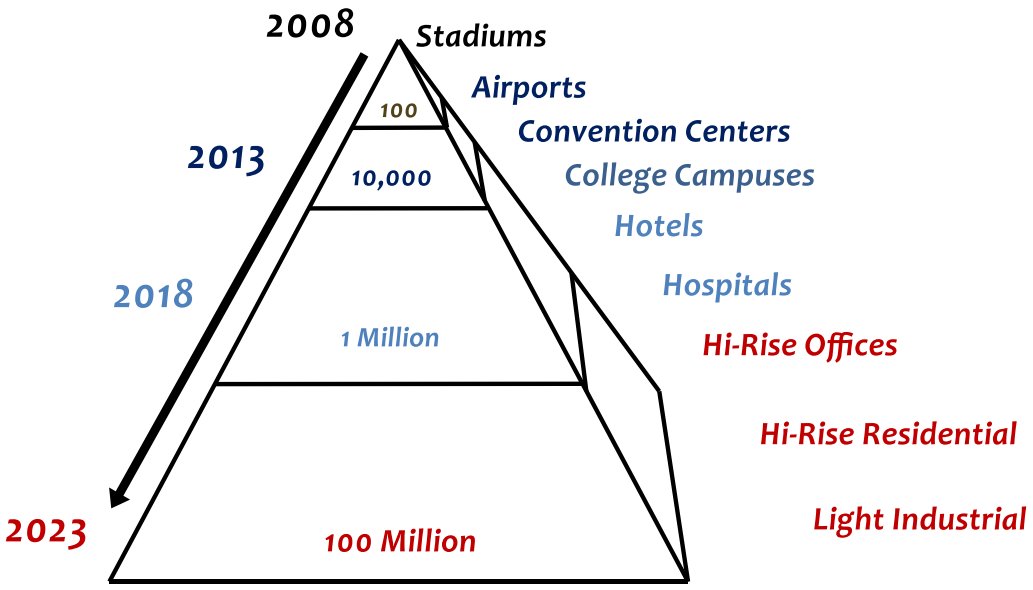
There's another important factor to consider. Some countries like Japan and Korea have been slower than the United States in releasing wide tracts of new spectrum.

In fact, the balance of mobile traffic density and spectrum availability is the single best metric to follow, in predicting the need for small cells. In Korea and Japan, Wi-Fi and small cell deployment began in meaningful quantities wherever data density reached 0.01 to 0.02 Gbps per square kilometer, per MHz of licensed spectrum (0.01 to 0.02 GkM).

Mobile Experts uses Gbps/km2/MHz or GkM as a key metric to predict how an operator is likely to deploy small cells. So far, this metric has been highly correlated to the first deployments of thousands of small cells in at least four different countries.

Mobile Coverage Indoors

One of the key drivers and uses of small cells is for indoor mobile coverage. Mobile Experts has been using the following figure to illustrate mobile infrastructure investments for in-building applications for some time. Mobile Experts has observed over the years that mobile infrastructure investment is trending 'down' towards less dense environments where small cells may be sufficient to provide adequate user capacity, and mobile data throughput experience. Although there are third-party providers like Boingo and Extenet that invest in mobile infrastructure systems at some of these places, the scale of deployments has been slow to take off as sustainable business models have been slow to converge.



Source: Mobile Experts

Figure 1. Illustration of In-Building Market Trend

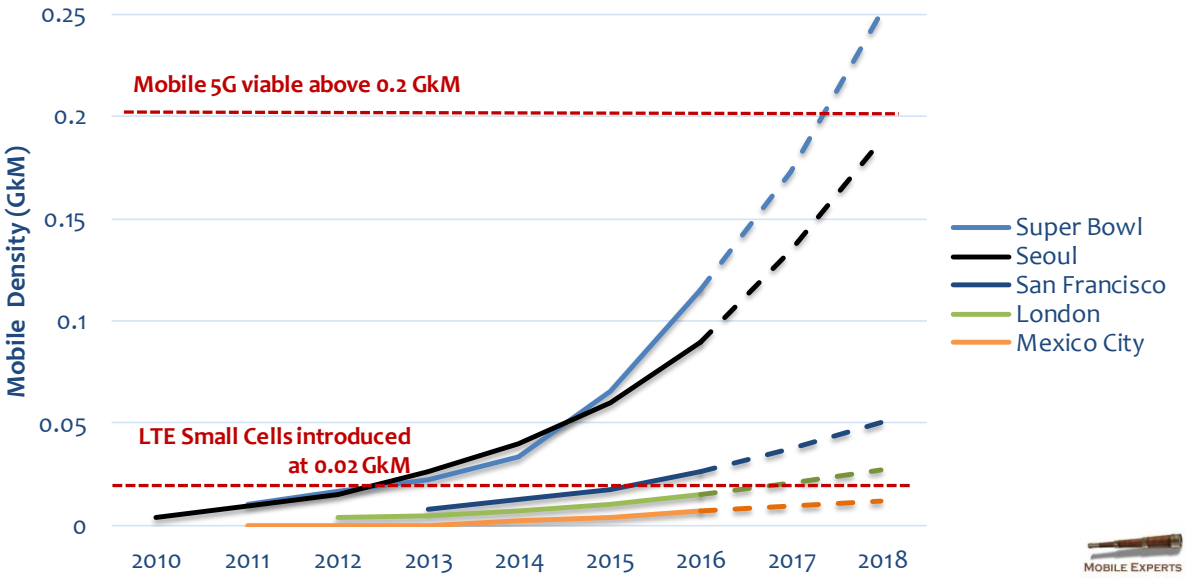
Excluding smaller venues (those less than 50K square feet of floor space), Mobile Experts estimates that there are about 30 billion square feet of floor space in the USA alone that have poor mobile coverage indoors. Reaching these 'down market' venues requires low-cost solutions that are easy to install and manage. So far, traditional in-building DAS solutions have been too expensive, and Wi-Fi has been unable to provide seamless and consistent user experience for mobile voice services.

Mobile services are critical to many enterprises today. Hotel executives understand the importance of good mobile coverage. Having a good indoor mobile coverage can determine whether they can book conferences or not. Commercial building owners also insist on good mobile coverage indoors to attract prospective tenants. With most people forgoing landline connections for phone services, having good mobile coverage indoors is becoming paramount. Meanwhile, corporate enterprises increasingly rely on mobile phones instead of desktop phones for most communication needs. While Wi-Fi may provide 'good enough' performance for some of the locations, it has been inadequate to provide consistent and seamless user experience.

Enterprise small cell vendors have been making good progress toward 'multi-operator' small cell solutions. Mobile Experts predicts that mobile operators will continue to push for building owners to fund in-building coverage, which will in turn drive new innovations to open up third-party or direct enterprise investments in enterprise small cells to address the indoor mobile coverage need.

Outdoor Densification driven by GkM

As mentioned earlier, Mobile Experts has been using a mobile density metric called GkM to correlate to small cell deployments in key markets. This tool identifies when operators are likely to deploy outdoor and indoor small cells to offload traffic away from the macro RAN network.



Source: Mobile Experts

Figure 2. Mobile Density (GkM) Trend Worldwide

This metric has been quite predictive in identifying when operators are likely to require network densification via small cells to expand capacity for a given area.

Another trend that we have observed anecdotally is that the number of cell sites impacted by the density of mobile traffic growth is 'spreading' from dense urban centers to suburban areas as traffic growth is skyrocketing across geographic boundaries and time zones. What this means is that small cell densification needs to be extended beyond the 'hotspot' areas of today. Another way to think about this trend is that the traffic hotspots are spreading, and the number of hotspot areas are increasing!

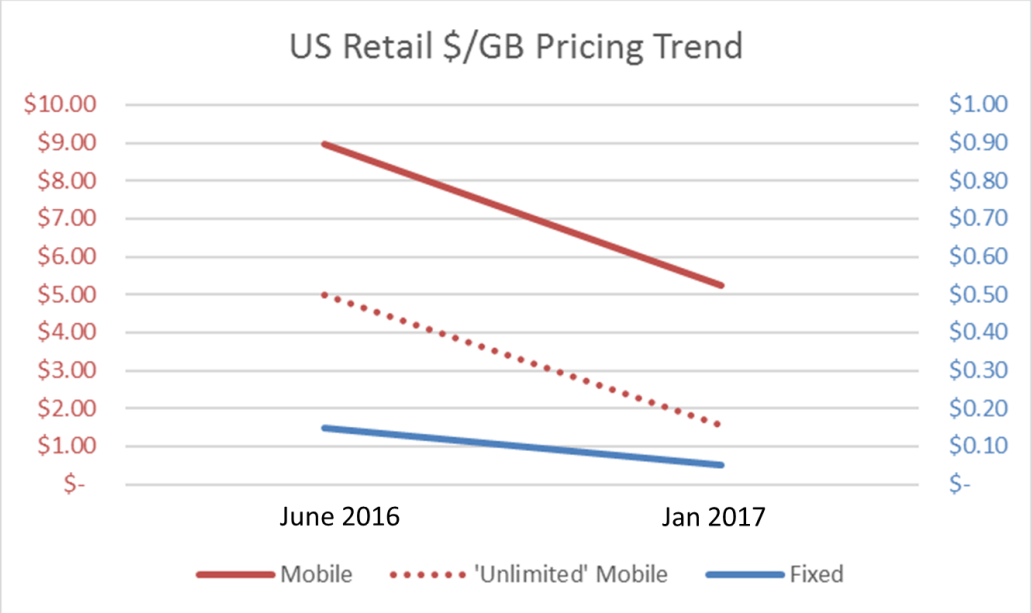
These trends point to further investment in small cell densification projects. Operators will be pressured to lower ongoing network expenses of operating ever increasing number of small cells. This is obviously not sustainable. Operators will increasingly look to third-party players like neutral host providers and traditional tower companies for to take on management of small cell network deployments and ongoing maintenance and management.

Carrier Competitive Intensity

Over many years, mobile operators have gradually lost key market advantages that they had over consumers to keep them from churning. Some of these include:

- Smartphone exclusivity – for a while, AT&T had an exclusive lock on iPhone; hence, customers wanting this iconic device had to get an AT&T mobile service contract;
- Phone number portability – this concept seems foreign now, but changing carriers sometimes meant letting go of one's phone number;
- Service contracts – with subsidized phone plans, carriers had two-year lock on subscribers before they could explore alternative service plans.

With these consumer 'barriers' now removed, consumers can more freely change service plans without the 'inconveniences' of making the changes. With the increasing utility of smartphone services and growing data demand, some customers are churning to find more attractive service plans. The re-introduction of "unlimited" plans in the United States is indicative of heightened competitive environment that the operators find themselves in, where only means of differentiation appears to be who has the cheapest "unlimited" service plans.



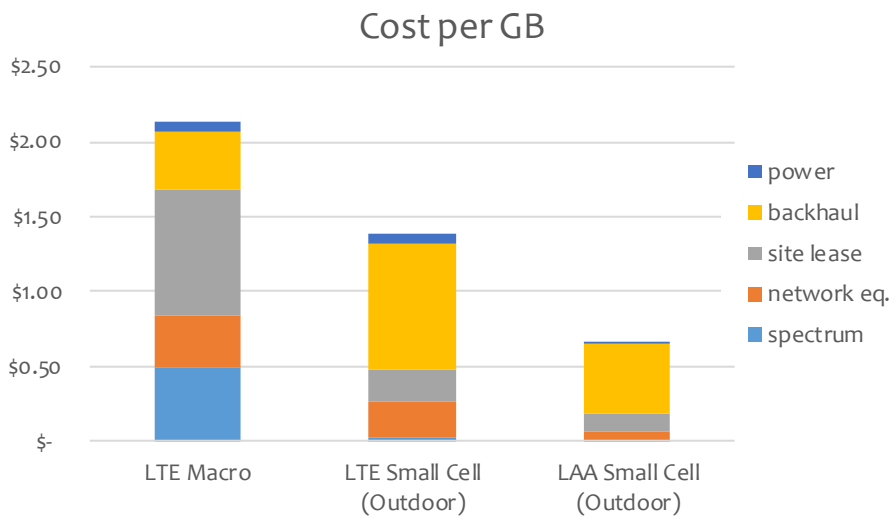
Notes: Mobile retail pricings based on 4-line family plans. Verizon's "plus 2GB per line" promotion included in data allowance calculation. Sprint's temporary "3rd,4th,5th line free" promotion excluded. T-Mobile's and Sprint's "unlimited" plans capped at 28GB/mo and 23GB/mo respectively per plan footnotes. Fixed retail pricing based on Internet standalone pricing with 1TB monthly cap allowance.

Source: Mobile Experts

Figure 3. Retail Mobile Data Pricing Trend in the USA

The average retail mobile data pricing ($/GB) in the United States declined by almost half in just six months, ending in January 2017.

If operators are competing on price alone, it will become critical for operators to increase network capacity at a lower cost to maintain margin. Sometimes this means making small cell investments in key strategic locations where traffic demand outpaces network capacity. Mobile Experts' cost analysis of 5-year TCO of LTE macro vs. small cell shows that small cells can reduce the monthly cost per GB per site basis by about 35%. Adding LAA to the small cell can reduce cost even farther.



Source: Mobile Experts

Figure 4. Comparative Cost per GB of Macro vs. Small Cell

In other words, operators may look to outdoor small cells for *targeted* densification to increase network capacity instead of upgrading the entire macro sector.

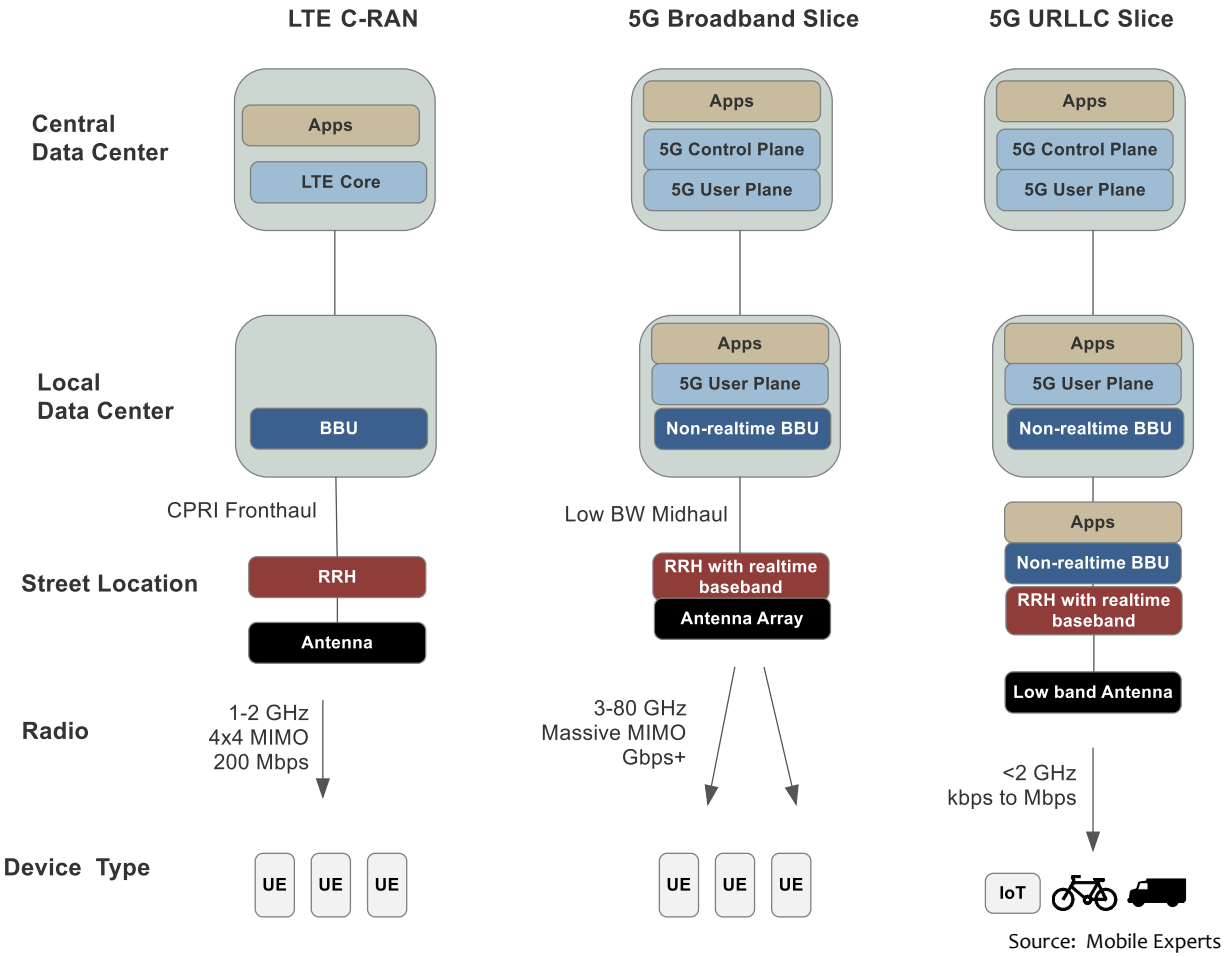
Preparation for 5G

As operators look to harness big chunks of spectrum above 20 GHz ('millimeter wave') bands for ultra-high capacity broadband services, the initial 5G millimeter wave networks will rely heavily on LTE core networks and LTE control signaling at 1-2 GHz bands. The RF propagation at 28 GHz and 39 GHz bands is significantly challenged and penetration of building materials, even at above 10 GHz, is poor such that maintaining control path would be extremely challenged. For these reasons, the initial 5G deployment is planned around dual band strategy – using LTE control plane at below 3 GHz band and aggregating data on the 5G link.

To achieve 5-10 Gbps data throughput in a wireless link, the 5G system will break away from the 450 MHz-2.7 GHz frequency bands used in 2G/3G/4G. For highest capacity, the 5G system will employ frequency bands somewhere above 20 GHz, as well as changes to the air interface in terms of higher order MIMO and a modified waveform. The basic

underlying principle of OFDM will be used, but with wider bandwidth the specific implementation will be modified to deliver extremely high throughput.

As a result, the radio portion of the network will include entirely new radio heads and baseband processing. In our diagram, we show a remote radio head which includes a portion of the PHY and MAC baseband processing, to keep the bandwidth requirements on the backhaul/fronthaul to a minimum. In addition, the centralized baseband processing pool has been virtualized, so when 5G arrives the baseband resources can be scaled up as needed to handle the extra load.



Source: Mobile Experts

Figure 5. Overall 5G Architecture for Broadband and IoT Slices

The LTE small cells deployed on street poles today will be basis for 5G remote radio heads in the future. Centralized RAN architecture with RRHs deployed for LTE services will be the foundation of 5G networks.

4 MARKET ENVIRONMENT

The small cell market in the past year can best be characterized as the year of deployments especially in China and Asia-Pacific -- notably at Reliance Jio in India. The diversity of small cell deployments across different market segments and regions around the world suggest that the market is maturing. Many operators are earnestly looking to deploy small cells in more non-residential applications to address indoor coverage issues or densify networks to drive more capacity. Major infrastructure OEM suppliers have been strategic in formulating small cell products that offer 'macro parity' to reduce operator costs associated with managing multiple networks. Meanwhile, a few upstarts have successfully established market positions in carrier indoor segment where close coordination with macro layer is not so strong.

As the market continues to march forward, new technology and ecosystem developments around LTE-U/LAA and 3.5 GHz CBRS may bring additional spectrum choices and new players and business models that may further accelerate growth in the market.

Spectrum Abundance – Licensed, Unlicensed and Shared

One of the key developments for the Small Cell industry in recent years has been the growing list of spectrum choices that operators have (a few samplings listed below):

- AWS-3 (2.1 GHz downlink / 1.7 GHz uplink) licensed spectrum (USA)
- WCS (2.3 GHz) licensed spectrum (USA)
- TDD 2.3 GHz, 2.6 GHz (China)
- 5.8 GHz unlicensed spectrum via LTE-U/LAA (Global)
- 3.5 GHz shared spectrum via CBRS (USA)

With LTE-U/LAA technology and CBRS ecosystem developments, spectrum no longer appears to be a limiting factor in small cell deployments. Operators can now leverage unlicensed and lightly licensed spectrum on top of their licensed spectrum holdings.

By taking spectrum cost out of the total cost of ownership, operators can further reduce the unit economics of delivering mobile data. Mobile Experts predicts that operators will allocate a small slice of licensed spectrum for control signaling and leverage 20 MHz chunks of the 5 GHz unlicensed spectrum for intensive downlink applications in franchise venues. It is possible that the increasing LTE-U/LAA adoption starting in 2017 will provide new momentum for carrier outdoor and indoor unit shipments.

Regulatory Outlook for Siting

As the industry works towards building high-capacity mobile networks, affordable and timely access to siting is becoming an important issue for the industry. In the USA, this issue is garnered much attention from government regulators at city, state, and federal

levels. Wireless infrastructure trade groups and infrastructure companies such as Mobilitie, Crown Castle, and Extenet, along with major mobile operators have many petitions and lobbying efforts to ease the regulatory approval process for access to the public right-of-way.

The highly competitive market environment in the USA is forcing some operators like Sprint to look for faster and cost-effective means to deploy tens of thousands of small cells quickly to bring wireless capacity 'on air'. By petitioning at the federal level, industry players are hoping that today's fragmented approach to regulatory procedures at individual municipalities can be streamlined. While this lobbying effort highlights the problem that operators and infrastructure providers face, Mobile Experts believes that historical precedence of public infrastructure projects being run by local municipalities and states will likely prevail.

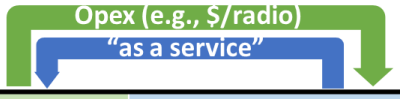
There is a growing acknowledgement among city and state officials that they need to get 'ahead of the curve' in wireless infrastructure siting and rate fees. Verizon's Smart City initiative with the City of Boston, including its 5G fixed wireless trial, is a good case in point. By working closely with a mobile operator, the City of Boston gains high-speed communication infrastructure and economic benefits that such infrastructure projects generate in terms of jobs and sales tax receipts. Verizon, in return, can expeditiously work through regulatory processes to complete the infrastructure buildout.

Overall, Mobile Experts believes the industry lobbying efforts and petitions at state and federal levels will yield positive outcome in the end. These activities will generate learning opportunities for both municipalities and industry groups to understand and identify working processes that can potentially be replicated across municipalities in key metro markets. Meanwhile, municipalities and infrastructure service providers need to work out reasonable rate fees for sites, and -- more importantly -- a streamlined regulatory process. Small cells will be placed in close vicinity to residences and businesses to enable faster mobile communications. It is in common interests of both cities and infrastructure providers to enable this. Mobile Experts believes that this issue will eventually be resolved, but it will take time for 'best practices' to be agreed upon. The FCC can potentially expedite this process through further rulemaking on this matter. The consumer demand for mobile services is strong, so this will work itself out.

Evolving Business Model for In-Building Wireless

With the potential possibility of leveraging lightly licensed CBRS spectrum bands, the in-building wireless opportunity addressed through third-party neutral host providers becomes more likely than before. Managed services through a neutral host provider requires integration of core networks between the neutral host provider and multiple mobile operators. The interworking between a neutral host and multiple MNOs can leverage the WLAN internetworking architecture as defined in 3GPP.

A managed service offering from a neutral host provider can be a great match for CBRS radios. Because the CBRS radios operate in the neutral 3.5GHz spectrum, there is no need for close coordination with mobile operators in RF design. The CBRS radio deployment can be led by neutral host providers or by enterprises themselves. CBRS essentially allows neutral host providers to independently deploy indoor LTE networks and support neutral hosting of multi-operator services. Effectively this is similar to neutral host or enterprises deploying Wi-Fi networks to support multi-operator device usage.



	Enterprise / Venue	Neutral Host Network (NHN) Service Provider	Mobile Network Operator (MNO)
Operations		• Network management • RAN optimization • Network maintenance • Seamless MNO interoperability • Charging	• KPI monitoring • Seamless NHN interoperability
Core Network *for local networks*		• Core networking • SAS coordination • Spectrum licensing • MNO network integration • LBO/enterprise application integration	
Radio Access Network (RAN) *at local venues*	• RF design and commissioning • Radio purchase and installation		

Source: Mobile Experts

Figure 6. Commercial Model for CBRS Neutral Host Network Operator

As listed above, an NHN provider takes ownership of various tasks required to operate a mobile wireless network and offer managed services to enterprises as an OPEX item (e.g., "$ per radio" or "$ per GB"). While a neutral host provider can take on full ownership of capital investments in core networking and RAN, in addition to on-going network management and operations, it is possible for enterprises to take on the radio network investment and/or installation, since CBRS LTE small cell deployment is expected to be similar to Wi-Fi.

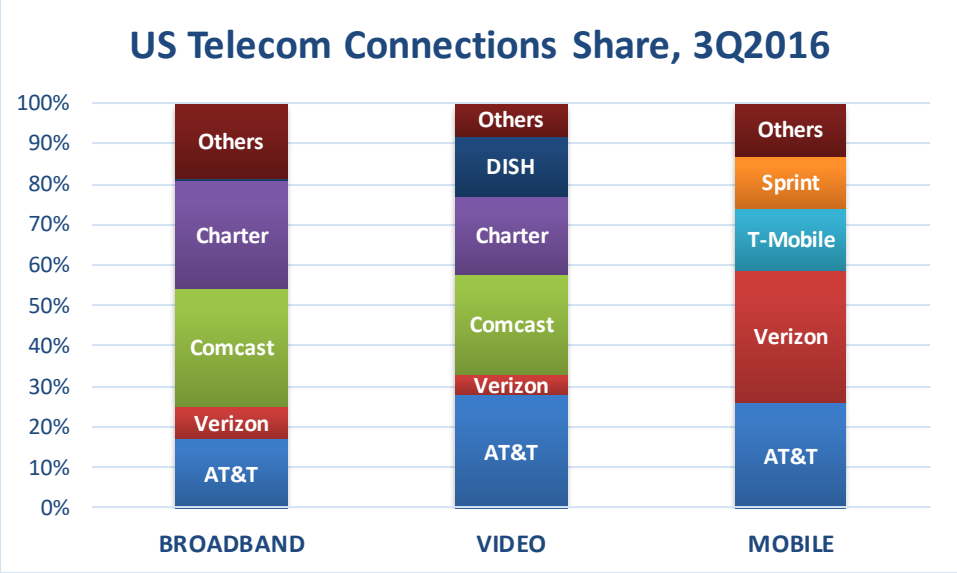
Neutral host managed services provide benefits to all key stakeholders involved.

- Enterprises can offload the complexity of building and managing LTE-based mobile network services, including complex internetworking with MNO core networks for seamless services in and out of buildings. In addition, the OPEX model associated with managed services provides a known expense outlook, without the uncertainty of building and operating a network.

- For mobile operators, dealing with a few NHN providers is more efficient than working with thousands of smaller enterprises, many of whom do not have telecom experience. Enabling LTE network coverage indoors can benefit mobile operators' subscriber experience.
- Finally, for neutral host providers, indoor network deployments can be independently led by themselves or by enterprises. If the operators are not involved in the planning and deployment process, time to market can be much faster. The freedom to deploy without coordination with mobile operators provide business agility to quickly deploy and activate LTE services. CBRS small cells, operating in the neutral spectrum, are naturally well-suited as a neutral host indoor mobile solution.

Fixed Mobile Convergence Trend

As fixed and mobile operator groups strategically position themselves in an evolving telecommunications landscape, where content is increasingly consumed over the top, on mobile devices, it is hard not to notice the waves of consolidation rolling across the industry. The traditionally siloed market segments across fixed broadband, wireless, and video markets are slowly being redefined as major players consolidate horizontally and vertically across the market segments. AT&T's acquisition of DirecTV, and the planned merger with Time Warner is a major guidepost in this network/media convergence trend.



Source: Mobile Experts

Figure 7. Telecom Share of Fixed, Mobile, Video Connections in the USA

The cable operators lead the fixed broadband and content distribution market with advantaged hybrid fiber coaxial (HFC) networks. Meanwhile the mobile operators

dominate the mobile wireless market--with differing strategic focus at AT&T and Verizon. AT&T remains more diversified in terms of network and media distribution strategies while Verizon is very focused on its wireless network along with a narrowly focused digital media/advertising strategy.

This fixed mobile convergence trend is not limited to the USA. The European region has in fact been at the vanguard of this macro trend as integrated operators there have been offering 'quad play' service bundles to retain existing customers and acquire new ones. Traditional incumbent operators with both fixed and mobile network footprints have been carefully investing in both sides of the fixed and mobile networks to optimize return on major capital expenditure projects. Meanwhile, predominantly fixed or mobile operators like Liberty Global and Vodafone are creating joint ventures or acquiring complementary fixed or mobile operators to bolster their network positions.

With this backdrop in the competitive telecommunications market, unlicensed technology solutions such as LTE-U/LAA and 3.5GHz CBRS are taking on a more prominent role as these new technologies and cheaper spectrum assets can potentially enable new market opportunities.

New Players and Business Models

Licensed spectrum has historically provided key differentiation and a barrier to entry for mobile operators. As new unlicensed and lightly licensed spectrum options come to market with LTE-U/LAA and 3.5 GHz CBRS, new players and business models that they champion may affect the small cell and mobile infrastructure market broadly.

Model 1: Traditional Mobile/Wireless Capacity Augment with LTE-U/LAA/CBRS

Mobile operators are the main drivers of this business model. While the traditional unlicensed Wi-Fi technology continues to handle the bulk of the wireless traffic, mobile operators are looking to more effectively harness the unlicensed spectrum through LTE-U/LAA technology. Mobile operators will mainly look to LTE-U/LAA technology for both the 5.8GHz and possibly 3.5GHz unlicensed bands.

Cable operators meanwhile are likely to focus on the 3.5GHz CBRS band as it offers additional spectrum that they can harness to augment their "Cable WiFi" footprint built on 5GHz and Wi-Fi. The 5GHz band is becoming increasingly congested, and the 3.5GHz CBRS bands offer a fresh batch of spectrum for the cable operators to continue their localized wireless network buildout.

A new entrant such as Google can potentially build out complementary 3.5GHz wireless networks as well. Targeted deployment at Starbucks, or at municipal sites such as LinkNYC kiosks can provide effective coverage in concert with Google Fi MVNO service. However, this requires a significant number of wireless hotspot deployments to make the

MVNO business case work. We see this as a low-probability event in the near term as Google needs to build strategic relationships with many municipalities and businesses which can be non-trivial and time-consuming.

Model 2: Enterprise Indoor Managed Services with LTE-U/LAA/CBRS Capacity Augment

This business model offers multiple players to address a sizable enterprise market opportunity. At a basic level, an indoor mobile coverage solution via 3.5GHz CBRS small cells can offer natively "multi-operator" indoor coverage solution that can potentially be cheaper than "heavy" DAS solutions that support multiple operators, bands and technologies.

With 3.5GHz CBRS requiring SAS coordination, we expect Neutral Host providers to play an active role as a necessary intermediary that can coordinate SAS and shared spectrum operation along with other managed service capabilities.

In addition, cable operators can open up other value-added offerings such as conferencing, cloud services, etc. Cable operators are targeting growth in business services catering to mostly small businesses. Because small businesses lack IT resources or knowhow, managed indoor wireless services from an Internet service provider becomes an attractive proposition.

Furthermore, there is a possibility that larger enterprises may look to 3.5GHz CBRS to build out "private LTE" networks that can more seamlessly support mobile voice services to satisfy the growing BYOD trend among enterprise workers. For now, this trend is held back by the lack of 3.5 GHz support in handsets. As a result, we expect the larger enterprises to continue to rely on traditional Wi-Fi equipment to construct its enterprise WLAN services in the foreseeable future.

Model 3: Fixed Wireless Broadband Substitute with CBRS

This business model leveraging 3.5GHz CBRS can potentially offer a pathway for new OTT entrants like Google to build out broadband networks wirelessly. As laggards in the fixed broadband space, mobile operators such as AT&T and Verizon are now moving to build up their fixed wireless capabilities. However, our expectation is that the US mobile operators will focus their efforts on millimeter wave bands--which offer a significantly greater spectrum bandwidth along with challenging RF propagation.

Cable operators will also likely participate in this business model as a hedge to protect their fixed broadband leadership position. Cable companies want an alternative to quickly meet broadband needs in additional locations that they struggle to cover today.

New over-the-top entrants in the fixed broadband market will be a tall order. Mobile Experts believes that current wireless ISPs largely serving rural or underserved markets

will leverage the newly evolving 3.5 GHz CBRS ecosystem to find more cost-effective solutions to meet their operational needs. We see a limited market opportunity in suburban or metro markets in the USA for a new entrant to solely base their business case on a fixed wireless broadband offering.

5 TECHNOLOGY BACKGROUND

Mobile network planning is a multi-faceted endeavor requiring relentless planning and execution. Multiple elements including spectrum, siting, backhaul, and network equipment must be secured, integrated, and quickly put in service to get ahead of the mobile data demand curve. Sometimes, operators employ different technologies, and architectures to optimize for cost and quality of service. Depending on the level of capital investment and architecture design choices, different operators may achieve different levels of network 'quality'.

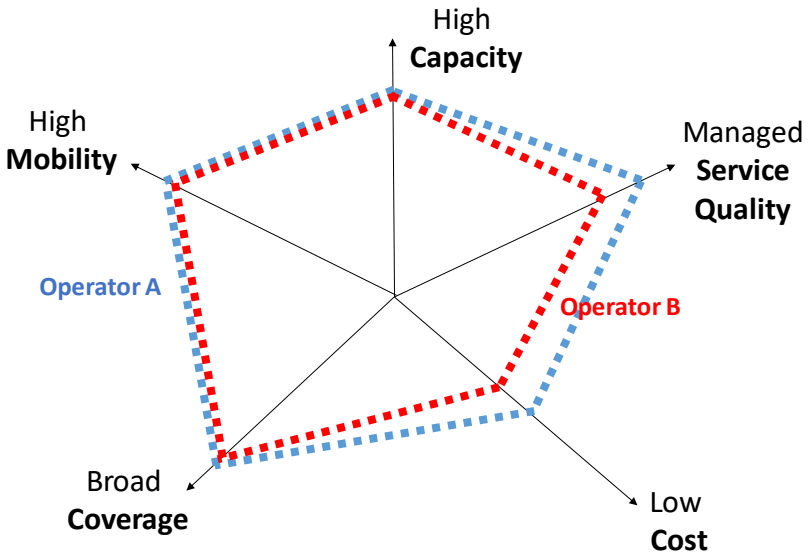


Figure 8. Dimensions of Mobile Network Service Quality

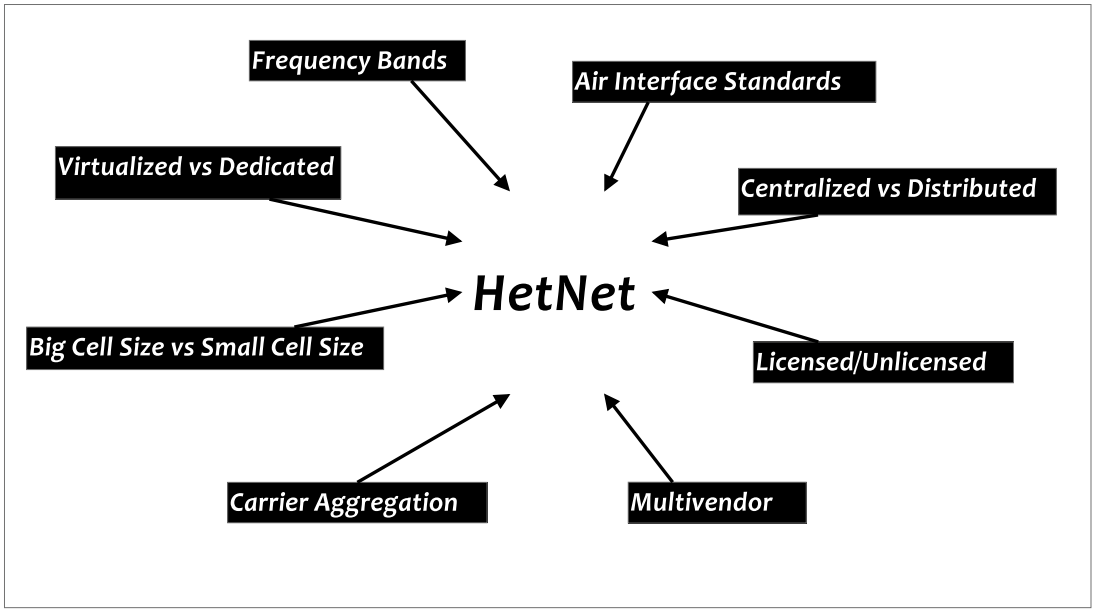
HetNet Architecture

Most major mobile networks are already Heterogeneous Networks or HetNets. Almost every major network includes multiple generations of equipment, as well as lower power solutions such as DAS, Remote Radio Heads, or Small Cells.

The HetNet is, by definition, a collection of different network elements that combine to provide mobile coverage in a constantly shifting mosaic. Existing macro sites provide wide area, high mobility coverage while small cells add capacity in key areas to boost data throughput or provide in-fill coverage. Wi-Fi access points are also a part of the HetNet, with operation on the unlicensed bands.

The picture gets more complex each year. This year, the 3.5 GHz CBRS ecosystem of shared spectrum band use became a step closer as FCC approved a select number of Spectrum Access System (SAS) vendors. Virtualization of the RAN and licensed/unlicensed

aggregation have now emerged as new innovations which will influence the HetNet. Don't forget that 20 years ago, the only issues to consider were the frequency band and air interface standard. Over time, the industry has added multiple dimensions of complexity to the "HetNet", making it heterogeneous in multiple different ways.



Source: Mobile Experts

Figure 9. Multi-dimensional Complexity of the HetNet

LTE-U and LAA

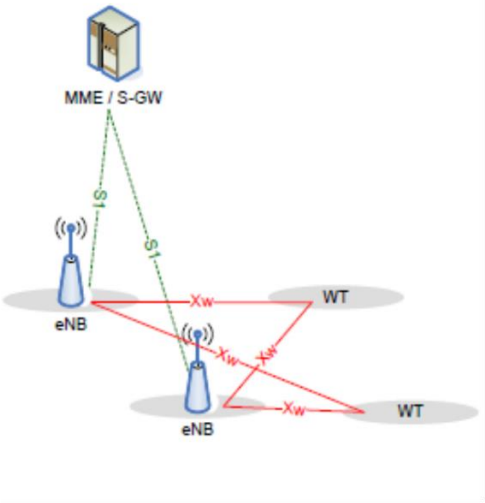
LTE-U and 3GPP-compliant LAA are built upon the carrier aggregation framework adopted in LTE Advanced releases (Release 10-13). Carrier aggregation combines more than one channel within the same band or with another band, effectively increasing the overall bandwidth available to a user equipment, thereby increasing bitrate. LTE-U seeks to aggregate the unlicensed band as a secondary cell for downlink while the primary cell connection reserved for control signaling and uplink is anchored to a licensed band. Due to regulatory differences, LTE-U supplemental downlink can be deployed in the US and Korea with dynamic duty cycling method called Carrier Sense Adaptive Transmission (CSAT), while Europe and Japan requires the "list before talk" (LBT) feature. Standardized LAA is expected to bring global scale to the LTE-U/LAA ecosystem, but the mobile operators especially Verizon and T-Mobile US have been very vocal about bringing LTE-U solutions to the market earlier. With the recent FCC approval, Mobile Experts predicts LTE-U/LAA deployments to begin and ramp in second half of 2017.

One of the key debates around LTE-U/LAA has been the idea of fair coexistence with Wi-Fi in the 5 GHz unlicensed band. Wi-Fi proponents, such as Google and cable operators who have largely relied on Wi-Fi to this point, for their wireless services have raised coexistence

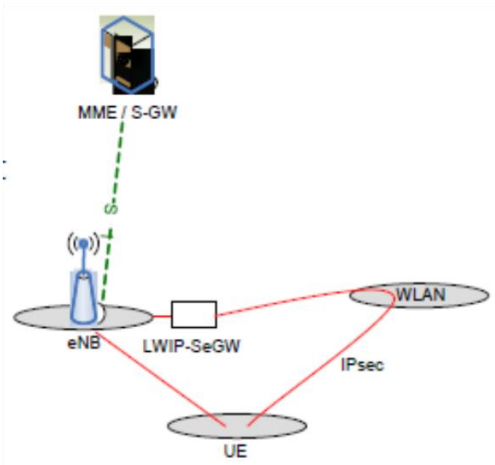
concerns.[1] The US Federal Communications Commission (FCC) has largely stayed on the sideline, asking the industry to sort things out. While the Wi-Fi Alliance (WFA) works towards a coexistence test plan by September 2016, LTE-U proponents are actively conducting field trials.[2] Based on slower than expected completion of the coexistence test plan, LTE-U commercial deployments aren't likely to begin until second half of 2017. The market time advantage of LTE-U may simply go away if the coexistence verification and FCC equipment certification approval are prolonged much further. In the end, however, LTE use in the unlicensed bands either as LTE-U or LAA will eventually happen as mobile operators push to harness unlicensed spectrum through handset upgrades and indoor and outdoor small cell deployments with LTE-U/LAA support embedded.

LWA and LWIP

In addition to the LAA specification, 3GPP Release 13 also defined a couple of WLAN interworking features to harness unlicensed spectrum use through optimally integrating Wi-Fi with LTE access network, namely: LTE WLAN Aggregation (LWA) and LTE WLAN Radio Level Integration with IPSec Tunnel (LWIP). Both LWA and LWIP essentially aggregate or switch data traffic over LTE and Wi-Fi airlinks at radio access network level. It is expected that LWA and LWIP would provide load balancing benefit between LTE and Wi-Fi networks through aggregation or switching. In effect, end users would experience a capacity boost from utilizing Wi-Fi network as if they were using LTE.



LWA



LWIP

[1] Key concerns raised by Wi-Fi proponents include the ability of deployed Wi-Fi devices to detect a free channel, and the aggressiveness of LTE-U/LAA devices to detect and avoid conflict with (Wi-Fi) "neighbors" through appropriate settings of energy detect threshold and backoff parameters. Broadcom has proposed -82 dBm energy detect threshold consistent with Wi-Fi preamble detect levels. According to Broadcom, 50% of Wi-Fi links are below -80 dBm.

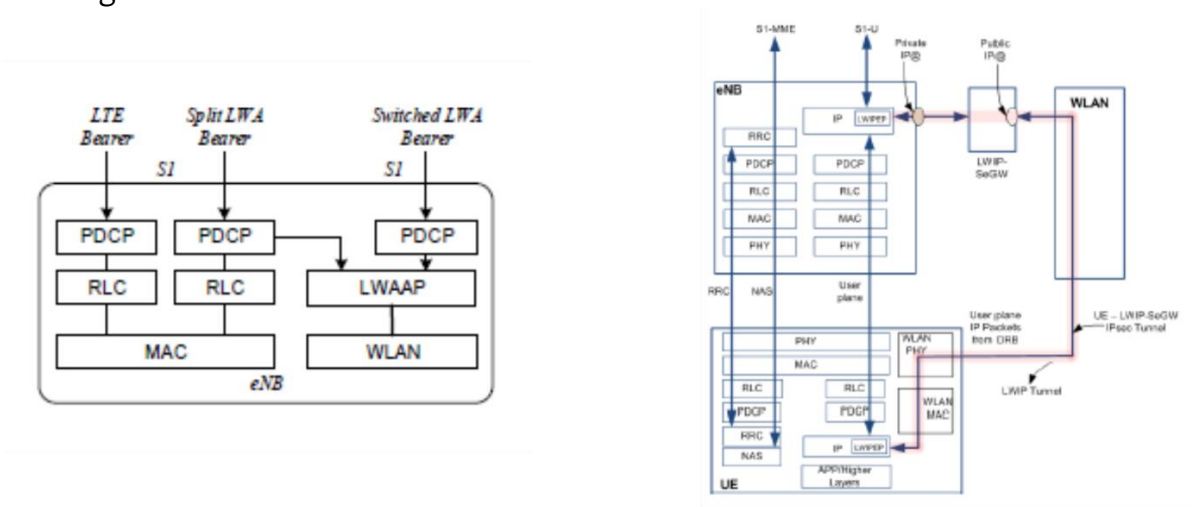
[2] Verizon is conducting LTE-U field trials in OKC and Raleigh, NC. Meanwhile, Ericsson is reporting trials and coexistence verification testing globally.

Source: 3GPP

Figure 10. LWA requires updated WLAN while LWIP works with legacy WLAN[3]

In LWA, as shown in Figure 10, the connection between LTE eNodeB and Wi-Fi access point is accomplished through a new WLAN infrastructure element called WLAN Termination (WT) using standardized Xw interface. Although a likely deployment scenario for this WT is to be incorporated into a Wi-Fi access point, this obviously impacts the Wi-Fi infrastructure requiring updated Wi-Fi access points. To facilitate faster time-to-market, LWIP is specifically designed to work with legacy Wi-Fi access points. Similar to the Wi-Fi calling architecture, LWIP uses IPSec tunnel between eNodeB base station and user device, and the IPSec tunnel is terminated in the LWIP Security Gateway (LWIP-SeGW) integrated in the eNodeB.

Beyond the subtle network architecture differences between LWA and LWIP, a key difference is that LWA aggregates LTE and Wi-Fi traffic at the PDCP layer while LWIP aggregates or switches at the IP layer, just above PDCP. LWA only supports aggregation on the downlink only, while LWIP supports both downlink and uplink aggregation and switching.



LWA **LWIP**

Source: 3GPP

Figure 11. LWA supports downlink only; LWIP supports both downlink and uplink

As outlined in the summary comparison table below, one of the key advantages of LWIP over LWA is that it can work with legacy Wi-Fi network infrastructure while LWA requires updates to Wi-Fi network infrastructure. Another key distinction of LWIP over LWA is that LWIP can support both downlink and uplink operations. Because of the flexibility of

[3] 3GPP liaison to IEEE on LWA and LWIP, March 2016

working with legacy WLAN infrastructure, we expect mobile operators who have direct or indirect access to carrier Wi-Fi networks to employ LWIP first.

	eNB control	WLAN measurements	Offload granularity	WLAN traffic direction	Feedback/flow control	Fast WLAN authentication	WLAN infrastructure impact	New network nodes
LWA	Yes	Yes	Split bearer	DL only	Yes	Yes[2]	Yes[4]	WT
LWIP	Yes	Yes	Bearer[1]	DL + UL	No	No[3]	No	LWIP-SeGW

1. When a bearer is configured to use IPsec, LTE DRB configuration remains, however eNB is not expected to send packets on LTE and IPsec simultaneously, as LWIP does not support re-ordering
2. After connecting to WLAN, LWA UE only performs 4-way handshake (if network uses the eNB based authentication)
3. After connecting to WLAN, LWIP UE performs WLAN native 802.1x EAP/AKA authentication, IP address acquisition and IPsec tunnel establishment
4. Impact due to eNB based authentication mechanism, if used by network. Optional UE feedback mechanisms (as opposed to network feedback) allow to limit WLAN infrastructure impact of LWA

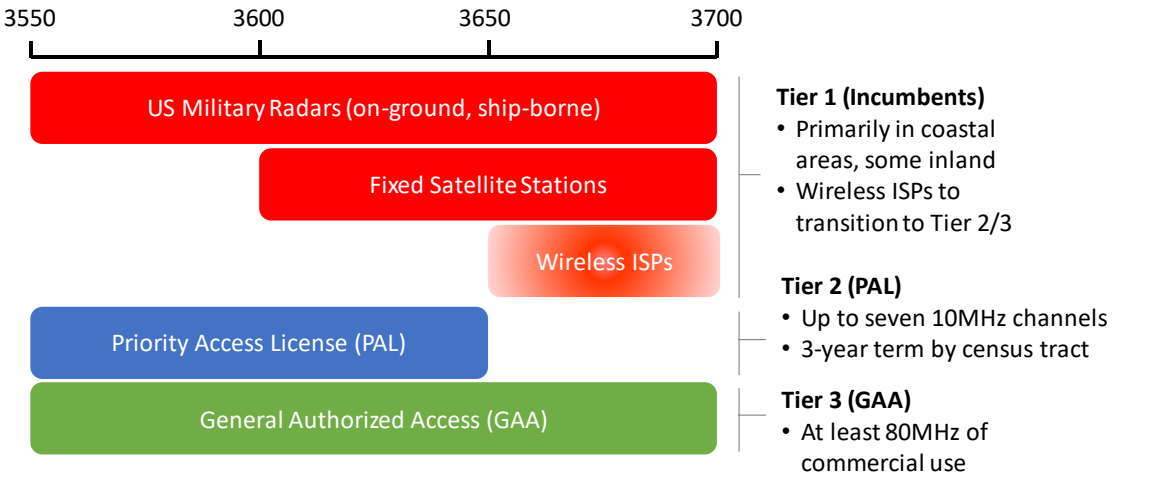
Source: 3GPP

Figure 12. Comparison of LWA vs. LWIP

While LWA and LWIP can be useful for operators looking to leverage existing Wi-Fi deployments, we have not seen much market traction for these technologies as operators may simply been looking to upgrade distributed radio units with latest LTE small cells supporting LAA features. There is also a discussion of LAA evolving towards support for dual connectivity, which will allow the use of LAA in non-collocated deployment scenarios with licensed spectrum.

3.5GHz CBRS

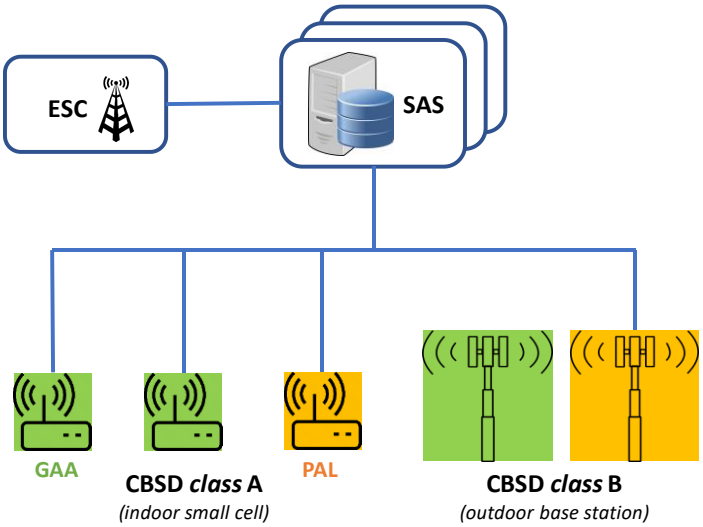
In 2015, the US Federal Communications Commission (FCC) formally established *Citizen Broadband Radio Service* (CBRS) for shared commercial use of the 3.5 GHz (3550-3700 MHz) band with the incumbent military radars and fixed satellite stations. For the first time, dynamic spectrum sharing rules have been defined to make additional spectrum available for flexible wireless broadband use while ensuring interference protection and uninterrupted use by the incumbent users. Under the plan, a novel three-tier sharing paradigm coordinates spectrum access among the incumbent military radars and satellite ground stations and new commercial users. The three tiers are: *Incumbent*, *Priority Access License* (PAL), and *General Authorized Access* (GAA) users.



Source: Mobile Experts

Figure 13. CBRS Tiered Shared Spectrum Licensing Structure

A key element of the CBRS spectrum sharing architecture is the *Spectrum Access System* (SAS). A SAS maintains a database of all CBRS base stations, formally referred to as *Citizens Broadband Radio Service Devices* (CBSDs), including their tier status, geographical location, and other pertinent information to coordinate channel assignments and manage potential interferences. To mitigate possible interference to tier 1 military radar systems, environmental sensors known as the *Environmental Sensing Capability* (ESC) will be deployed in strategic locations near naval stations, mostly along coastal regions, to detect incumbent activities. When incumbent use is detected, the ESC alerts the SAS, which then directs CBSDs utilizing impacted CBRS channels in that area to move over to other channels. The cloud-based SAS enforces the three-tier spectrum sharing mechanism based on FCC rules via centralized, dynamic coordination of spectrum channel assignments across all CBRS base stations in a region.



Source: Mobile Experts

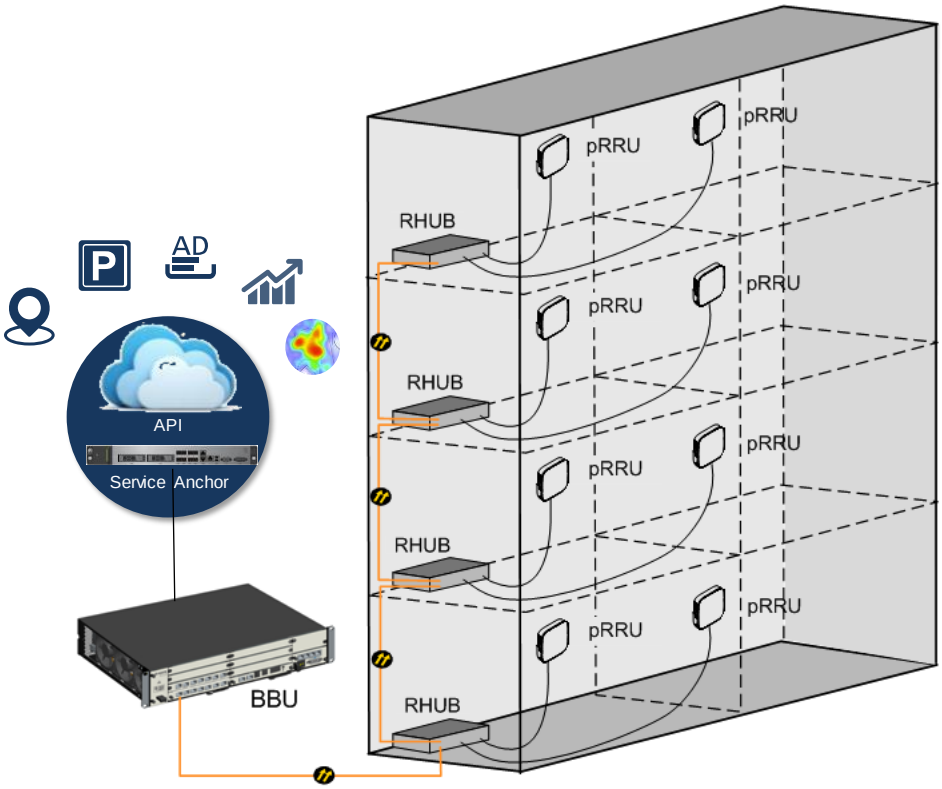
Figure 14. CBRS Functional Overview

The CBRS rulemaking defines two classes of base stations: *class A* and *class B*. A *class A* base station can be thought of as indoor or low power outdoor small cells with a maximum conducted power of 24 dBm (per 10 MHz) and maximum EIRP of 30 dBm (1 watt). This type of small cell is similar to "enterprise-class" small cells in the marketplace with 250mW transmit power with a typical 2 dBi omni antenna or up to 6 dBi directional antenna. Meanwhile, a *class B* base station is meant for outdoor use with a maximum EIRP of 47 dBm (50 watts). With a very high-gain antenna, outdoor CBRS base station can potentially be used for fixed wireless purposes. While indoor and outdoor base stations can be assigned to either GAA or PAL, we expect to see more indoor GAA deployments until ESC certification and PAL auctions get finalized.

Distributed Radio Systems (DRS)

Distributed radio systems like Huawei's LampSite and Ericsson's Radio Dot take the Centralized RAN architecture concept with low power RRH radio units one step farther. Instead of the RRH feeding an antenna directly, the RRH leads to a series of distributed RF antenna nodes to distribute RF signals "deep" within indoor venue locations. They are very similar in concept to other "distributed" systems like DAS. While the architecture and functional aspects of DRS is similar to active DAS systems, Mobile Experts generally view DRS as a single-operator system vs. multi-operator capabilities for DAS.

A typical DRS system, like the Huawei's LampSite base station shown below, consists of a baseband unit (BBU), RRU hubs, and multiple remote radio units. LampSite allows multiple remote radio units to serve one cell with each cell individually served by each remote radio unit, which increases SINR. LampSite separately demodulates signals from multiple remote radio units and then combines the signals in the BBU without increasing background noise. Also, the macro parity aspect of LampSite allows closer coordination with macro networks to reduce operations and management costs.



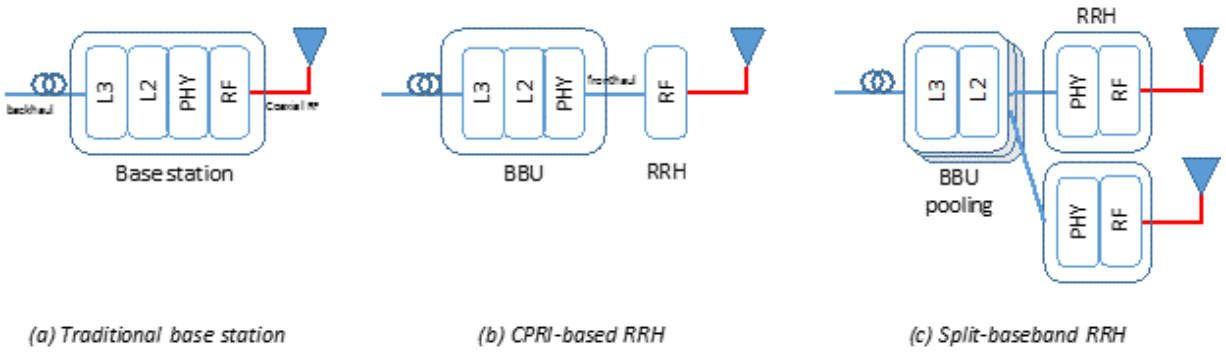
Source: Huawei

Figure 15. Huawei's LampSite base station

CPRI and Split Baseband RRH

DRS systems like the Huawei's LampSite and Ericsson's Radio Dot are product realizations of CPRI and split baseband RRH architectures. A base station architecture has evolved over the years from a large system with multiple racks of equipment to a modular design with essentially two main components: digital baseband unit (BBU) and a remote radio head (RRH). This evolution is largely driven by economics to reduce site and power costs, improve flexibility, and increase performance. In a traditional base station architecture (**Error! Reference source not found.**a), the RF coax line was often strung a long way up a tower to antenna, causing RF loss. To alleviate this problem, and to minimize power consumption and site lease costs, vendors separated RRH from BBU to handle RF processing near the antenna.

The fronthaul that interconnected BBU from RRH was devised to be "open" though initiatives such as CPRI and OBSAI, however, actual implementations are often been proprietary in nature.

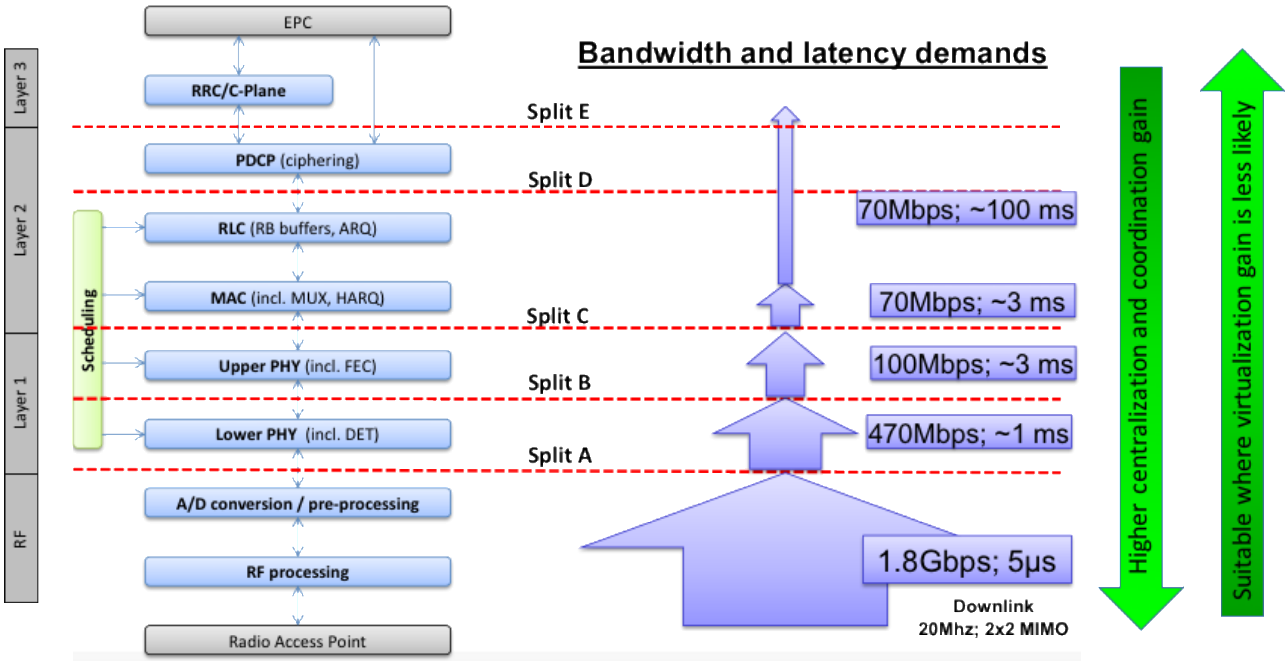


Source: Mobile Experts

Figure 16. Base station evolution

While the CPRI-based RRH architecture allows for cost savings by pooling baseband processing centrally for a quick replacement and maintenance, it does have a major drawback in that CPRI requires a significant demand on link throughput and latency. For instance, a single LTE channel with 20MHz, 2x2 MIMO, would require close to a 2.5 Gbps CPRI link. As we think about massive MIMO processing envisioned with 5G base stations, the CPRI-based RRH architecture would drive huge throughput and tight latency demands.

To remediate the high front haul costs of fiber associated with distributed RRH architectures, multiple vendors have expanded upon the traditional CPRI based RRH model where IF and RF processing are separated from base station to splitting at baseband (Figure 16c) to minimize the fronthaul bandwidth and latency requirements. Although the BBU-RRH split as depicted in Figure 16c is between MAC and PHY, there is no definitive standard on this today. In this early stage of the market development, we may see multiple vendor solutions with different split allocations, most of which put some Layer 2 features into the RRH to keep "real time" functions at the radio location. As we examine the myriad possibilities of the split, it is clear that keeping more of the baseband processing in the BBU away from the RRH drives up the fronthaul transport requirements in terms of bandwidth and latency demands as shown in **Error! Reference source not found.**.



Sources: Mobile Experts, iJOIN

Figure 17. Split-baseband alternatives and rough bandwidth and latency requirements

It is clear from myriad vendor implementations of CPRI and Split baseband RRH architectures that small cells are likely to adopt split baseband RRH architectures as fronthaul bandwidth requirements will surely go up as operators continue to increase RF capacity at the edge.

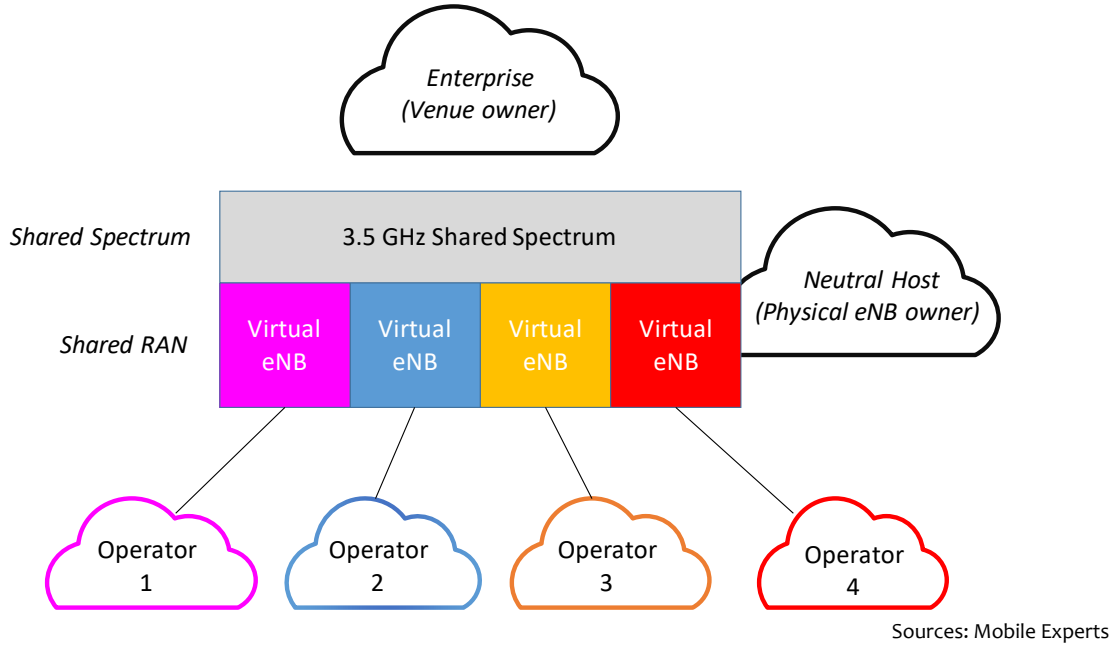
Virtualized Multi-Operator Small Cell

Small cell development has progressed without paying much attention to the difficulties of handling traffic for multiple operators on the same radio equipment. Small cell architectures are slowly evolving in that direction. Here are a few examples:

- MORAN and MOCN: Through RAN-sharing arrangements, two operators can use the same radio infrastructure and provide service to their customers without investing all of the money for just one service. MORAN (Multi-Operator Radio Access Network) allows each operator to use a dedicated radio channel on the same hardware, while MOCN (Multi-Operator Core Network) allows for fully shared radio channels while maintaining independent core networks.
- Convergence of Small Cells and DAS: Small cells can be used as signal sources in a DAS network. In some cases, the level of capacity and coverage in the building can line up so that this solution is the most economical and flexible way to outfit a building for multi-operator coverage.

- Multiple Small Cells: Multiple operators accept a few small cell solutions. If two or three major operators all agree that a small cell solution works with their macro network, then the small cell vendor can place multiple radio units in a building, interleaving the service for Operator A and Operator B. This outcome is starting to look more likely for major enterprise small cell vendors such as Cisco, where the small cell is attached to Wi-Fi access points that are spaced very close together.

Extending the RAN infrastructure sharing concept of MOCN with shared spectrum of 3.5 GHz CBRS can potentially yield streamlined process and clear ownership responsibilities that are sometimes problematic in traditional neutral host business models. With shared spectrum, it is potentially possible for a neutral host provider to take stock of physical small cell RAN that can be virtualized for N number of operators. Since the spectrum is theoretically 'free' in GAA use, operators do not have to share any of their prized licensed spectrum and simply use the shared RAN as if it is provisioned only for that given operator. The neutral host provider can be the actual owner of the RAN and create network sharing arrangement with each of the operators and in return provide mobile services to enterprise customers who grant venue rights to place virtualized enterprise small cells within its venue and pay service fee for use of multi-operator mobile services indoors.



Sources: Mobile Experts

Figure 18. Virtualized Multi-Operator Small Cell (with Shared Spectrum)

Pre/5G Low Power RRH

While the 5G standards work has not been finalized just yet, a high level of consensus has already been reached on standards, and all leading players have bought into an acceleration of the standardization timeline. We expect the industry to settle on the following key features:

1. Massive MIMO: Also known as full-dimension MIMO, FD-MIMO, or 3D-MIMO, the use of more than 8 antenna elements per sector allows for a dramatic increase in spectral efficiency, because the spectrum can be re-used effectively by breaking the sector into narrow beams. This feature will be most useful in the macro market, but we expect some use of Massive MIMO in high-density 5G deployments due to the high spectral efficiency benefit.
2. OFDM with Options: In the New Radio (NR) frame structure, the number of subcarriers, bandwidth, and subcarrier spacings are all expected to be flexible. Cyclic prefixes are likely to be optional, with filtering either at the subcarrier level or in groups of subcarriers. Overall, the intention is to modify OFDM to improve out-of-band spurious emissions, keep Peak-to-Average Ratio (PAR) as low as possible, and allow for very flexible use of spectrum, from ultra-reliable low latency communications to very high throughput links.
3. Dual Band 5G Networks: Mobile operators that have plans to deploy 5G networks in the mm-wave frequency bands have conducted numerous trials, and universally have concluded that 5G requires either LTE as a control plane, or an additional spectrum allocation below 6 GHz for control signaling. The propagation above 24 GHz is too poor to guarantee a continuous control channel in a macro network. However, for indoor small cells (such as an airport or subway terminal), a stand-alone mm-wave small cell is a possibility that could come in the future.

As multiple mobile operators pursue different business cases for 5G, we foresee the 5G infrastructure market to break into three major aspects:

1. Fixed broadband deployment: This will be addressed with the 5GTF and other pre-5G formats in the USA, but will eventually merge with 5G NR. We have included these radio head shipments in our estimates of mobile 5G infrastructure, because eventually these two applications will merge into a common network.
2. High power RRH shipments: Above a power level of +52 dBm, the operator is targeting "macro" level of coverage. Almost all of this high-power deployment will take place below 6 GHz due to the limitations of power in the millimeter-wave bands.
3. Low power RRH shipments: Below +52 dBm, the mobile operator will be targeting small coverage areas for each site, so we treat this segment of the 5G market as an extension of the small cell market, and includes these units in our Small Cell market forecast.

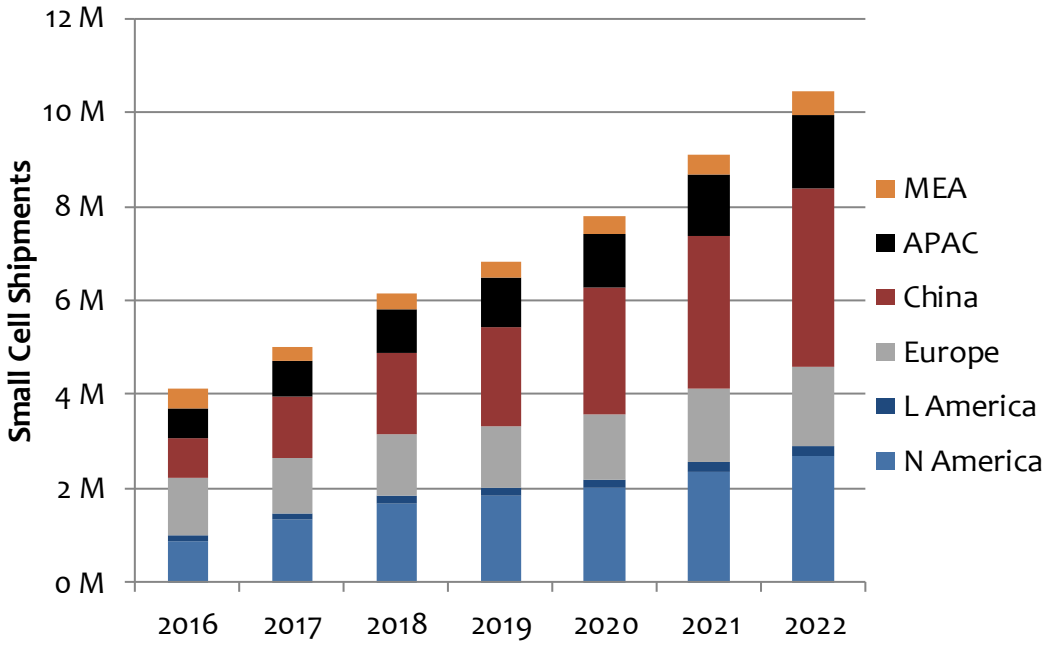
Low power 5G RRH units, operating below 6 GHz, will likely be employed as "small cell densification" for the 5G macro network. In some instances, RRH units operating in the

millimeter-wave bands will also be employed for small cell densification regions for very high-capacity links, but the control signals are going to remain on either low-band 5G or LTE.

Overall, the small cell opportunity in 5G will center on the mm-wave bands for the near term, because deployment below 6 GHz will generally fall into the "macro" category at EIRP levels above +52 dBm. Almost all deployment above 20 GHz will be classified as "small cell" due to the low power dictated by the laws of physics at mm-wave frequency bands. In the long term, we can expect densification in the sub-6 GHz bands, but traffic density will need to increase by another order of magnitude to justify this kind of deployment, so we expect sub-6GHz small cells to ramp sometime after 2022.

6 REGIONAL OUTLOOK

Asia-Pacific and China regions are beginning to lead the small cell market as major network buildouts at Reliance Jio in India and densification projects in China are driving the growth. Large numbers of small cells are being deployed for strategic 'in-fill' projects as the operators in India and China complete their initial LTE coverage rollouts. The outsized growth of these regions is reflective of large scale networks and subscriber bases that the operators there support. North America and Europe continue to dominate the rollout of residential femtocells and enterprise small cells.



Source: Mobile Experts

Chart 4: Small Cell Forecast, Global by Region, 2016-2022

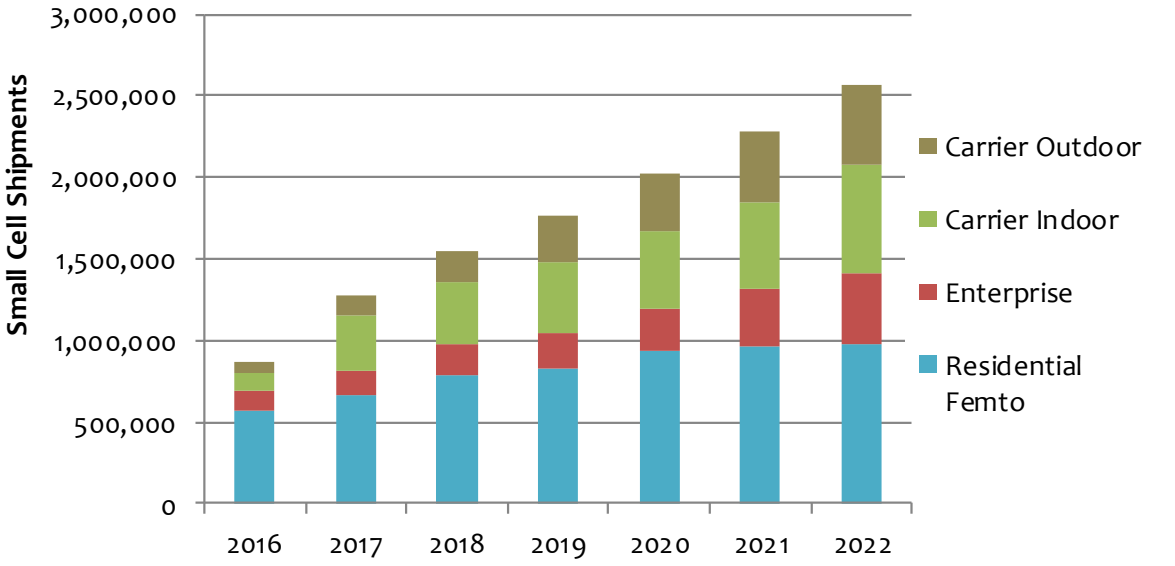
As operators look to strategically deploy capital expenditures beyond initial LTE macro coverage rollouts, Mobile Experts expects the carrier indoor segment to outpace the outdoor small cell segment as operators look to expand coverage footprint indoors to target high-value customers at key enterprise venues. Outdoor small cells will also see growth, albeit at a slower pace than Carrier Indoor small cells, as operators continuously look to densify their network footprint towards 5G services, which will likely operate at higher frequency bands below 6 GHz, and in conjunction with millimeter wave bands at 28 GHz and 39 GHz.

(It should be noted that, in comparison to our last year's report, shipment figures are skewed by the fact that we now account for individual DRS radio units which significantly skews the figures for regions that have widely adopted the DRS architectures – i.e., China and APAC.)

North America

While China and Asia-Pacific regions dominated headlines in small cell deployments in the past year, the North America region, specifically the USA, continues to be an important market for small cells as American operators wield large capital budgets yearly. The highly competitive market environment, characterized by unlimited data plans, is expected to force the Tier 1 operators to accelerate their wireless expansion plans. In addition to deploying AWS-3 and WCS spectrum and refarming 2G/3G spectrum, Mobile Experts expects operators to strategically deploy indoor and outdoor small cells to expand capacity in traffic 'hotspots'.

In 2016, the overall small cell market in North America was flat year over year. The recent deceleration of residential femtocells in North America extended in 2016. With wide support of voice over Wi-Fi and ever-expanding fixed broadband bandwidth, some operators seem happy to offload some of the mobile services to Wi-Fi infrastructure.



Source: Mobile Experts

Chart 5: Small Cell Forecast, North America, 2016-2022

The decline in residential femtocells were made up with modest uptick in Carrier Indoor and Outdoor small cell shipments. Operators continue to strategically deploy indoor and outdoor small cells to help manage traffic hotspots. Depending on siting and permitting constraints, some operators are leveraging outdoor small cells directed towards specific indoor venues to provide 'outside-in' coverage. And, in other cases, they are (a) deploying enterprise-focused small cells to address indoor mobile coverage issues and (b) using indoor small cells to offload traffic away from busy macro cells nearby.

One of the biggest disappointments in 2016 was a strategic change in Cisco's "enterprise direct" strategy. It appears that Cisco will not be taking a prime role in pushing licensed small cells directly to enterprises. Rather, it will focus on opening its 'clip on' interface to small cell vendor partners to attach their small cells to Cisco's Wi-Fi access points. As a result, our forecast for enterprise segment has been updated to grow at a slower pace than previously forecasted.

For 2017, Mobile Experts forecasts a significant uptick in small cell shipments in North America. There are multiple factors driving this growth:

- Mobile Experts predicts that T-Mobile and Verizon will focus on residential femtocells and carrier indoor small cells to enable LTE-U and later LAA.
- Sprint is expected to roll out a meaningful number of hi-power and low-power outdoor units to expand its mobile capacity. Its partner Mobilitie has been active in regulatory approval process with many municipalities.
- Cable operators have been testing multiple small cell products for both CBRS in the lab. Although we do not expect heavy volumes in the near term, their wireless entry may provide uplift in small cell shipment figures in 2018 and 2019.

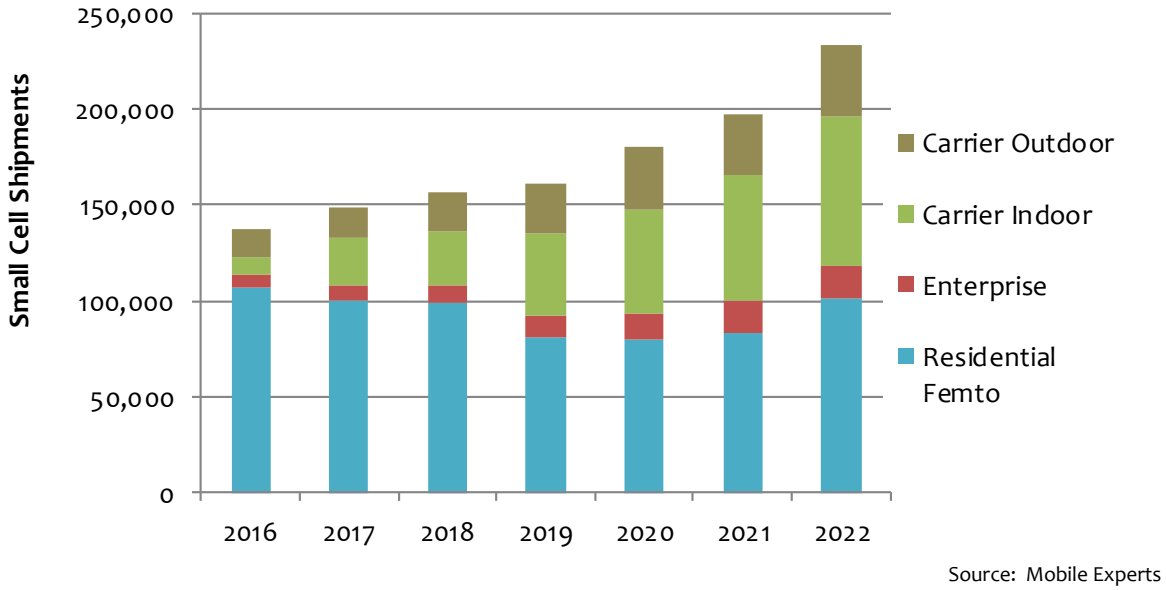
With Dish's recent announcement of its plan to deploy IoT network to meet the regulatory requirement to deploy spectrum that it had acquired many years back, Mobile Experts predicts their Dish's impact will be small, especially in the small cell area. Dish's spectrum holding will be a part of evolving telecommunication landscape that will take some time to play out, and the main deployment for IoT is likely to be a macro network.

Latin America

Latin America has generally lagged other regions due to lower traffic density and low ARPU market conditions. While developing economies like Mexico has bolstered new mobile infrastructure investments, these investments have been mostly broad macro investments to provide broad LTE coverage in key population centers and highways that connect them. Investments in mobile data infrastructure continues to be made, but focused investments in small cells are expected to take some time as data and smartphone penetrations reach higher levels that warrant strategic investments in small cells especially as the operators move to LTE.

While 2G/3G picocell and microcells will continue their decline as operators increasingly target their infrastructure towards LTE, we forecast LTE small cells, especially indoor units, to be increasingly deployed by carriers to target high-value enterprise customers at key venues to satisfy the growing mobile data usage. Residential femtocells meanwhile will maintain steady annual shipments to satisfy high-end consumer segment. In the end,

more carrier-grade small cells are expected as a low-cost way to deploy both Wi-Fi and mobile data coverage.



Source: Mobile Experts

Chart 6: Small Cell Forecast, Latin America, 2016-2022

The recent macro-economic malaise in key Latin American markets like Brazil and Argentina has hampered mobile infrastructure investments. Those conditions have resulted in light deployment of small cells. While the residential femtocell category constitutes a largest segment today, we expect the carrier indoor units to dominate the annual shipment in the latter half of our forecast period. Moreover, we expect some operators to look to carrier outdoor units--especially high-power carrier outdoor 'mini macro' units--to provide strategic mobile coverage and in certain cases, higher capacity augmentation solution to high-trafficked areas. The shift in focus from residential to carrier deployments is starting to happen in key urban locations as mobile traffic density reaches a level of 0.02 Gbps/km^2/MHz as we have observed in other markets.

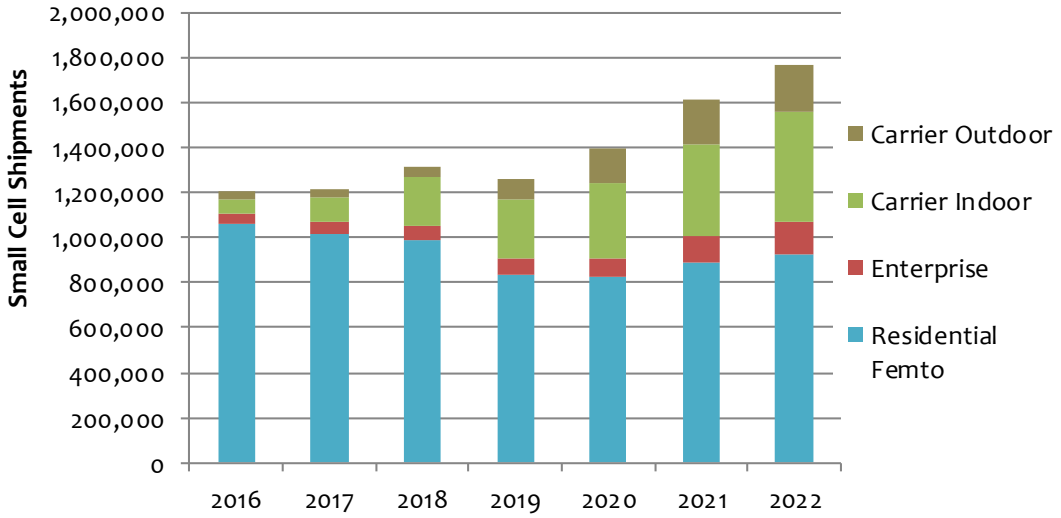
Europe

The small cell market in Europe has been characterized by outsized deployments of residential femtocells by such upstarts as Free Mobile in France and other similar players in heavily competitive telecommunication markets such as UK. Due to highly competitive market conditions, somewhat influenced by a 'hands-on' regulated market environment, the fixed mobile convergence trend has been far more prevalent in this region. With relatively low ARPU and incremental revenue opportunities like roaming for example, substantially limited by regulations, both fixed and mobile operators have been looking to 'quad play' services to acquire and retain the subscriber pool. For example, a predominantly fixed operator like Liberty Global has been strategically acquiring mobile

operations, establishing MVNOs, and forming joint ventures with mobile operators, to broaden fixed and mobile service offerings. As another example, Vodafone (predominately mobile-focused) has recently acquired several cable operators in Spain and Germany to broaden its fixed broadband footprint.

While residential femtocells will continue to play an integral role in fixed mobile convergence markets, we expect integrated operators with mobile infrastructure to increasingly look to carrier indoor deployments of small cells to expand mobile coverage footprint in key enterprise venues like hi-rise office buildings and highly trafficked transportation hubs. Many Tier 1 operators in Europe consider outdoor small cells to be a less optimal means to expand the coverage-capacity dimension, so pent-up demand is growing for in-building mobile wireless service.

Enterprise-focused small cells have been deployed in meaningful volumes in Europe, to extend both 3G and LTE services. While the direct-to-enterprise channel is not as well developed as North America, we expect major markets like the UK to quickly adopt this model as the ecosystem of OEM vendors, operators and third-party integrator/service companies like OpenCell in the UK becomes more mature.



Source: Mobile Experts

Chart 7: Small Cell Forecast, Europe, 2016-2022

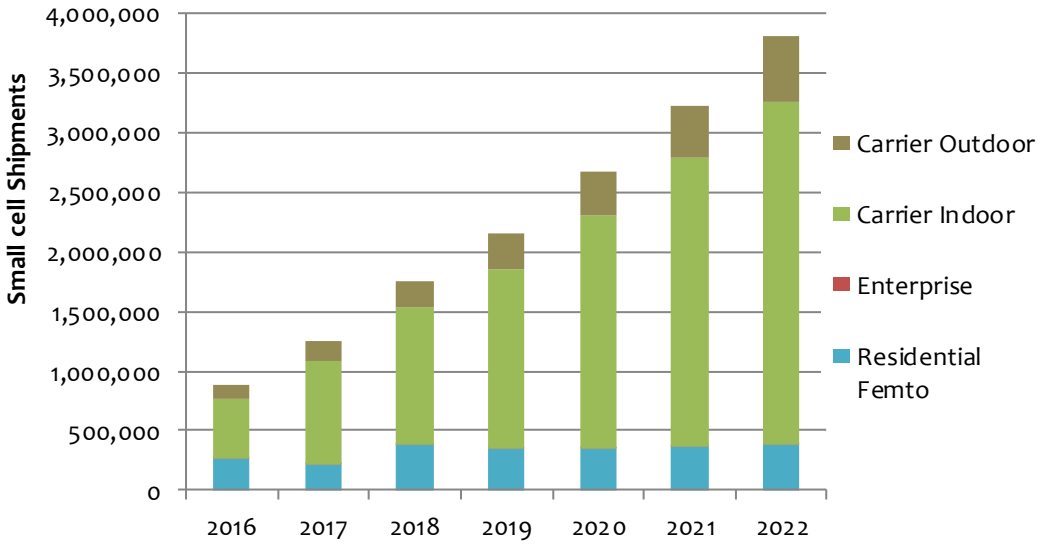
As traditional 3G microcells and picocells fall out of favor as the operators divert their capital expenditure toward strategic densification efforts, we expect carrier indoor deployments to increase to support strategic densification projects. As 5G use cases and trials ramp in 2019/2020 timeline, we expect the operators to deploy carrier outdoor small cells in preparation for the dense 5G deployment dictated by higher spectrum bands. Moreover, we expect many of these carrier outdoor deployments to be split-baseband RRH in nature as operators look to leverage varied fronthaul options including copper-based G.fast, fiber and wireless backhaul.

China

China continues to drive fast LTE adoption as affordable LTE smartphones and broad LTE coverage investments have resulted in a huge LTE subscriber base. Since launching LTE services in early 2014, the three main operators in China have quickly ramped up LTE customers to a combined 800 million subscribers by early 2017. According to China Mobile's owned figures, its LTE subscriber base now stands at about 560M customers, which constitutes 65% of its total mobile subscriber base. As operators conclude their 'macro coverage' phase, we expect them to increase their focus on small cell investment for 'dense in-fill' phase through small cells.

China Mobile is the leading mobile operator in China by a long shot, and has been leading many of the key mobile infrastructure initiatives like LTE, small cell deployments, and 5G. In 2016, the market had expected a sizable small cell investment by China Mobile through its "nanocell" initiative. While the market had expected a follow-on tender of about 1 million units, the actual order turned out to be only 100K units. The initial phase yielded a minimal shipment of small cells, but China Mobile continues to leverage distributed radio system (DRS) such as Huawei's LampSite product to target indoor facilities like retail malls. By leveraging value-added services like location-based services and indoor positioning enabled through a centralized DRS architecture, China Mobile is looking to reduce site cost and capture incremental revenue opportunities via retail venue owners, beyond consumer subscriptions.

China Telecom and China Unicom have been occupied with macro FDD-LTE rollouts, so they have been less focused on small cells than CMCC. However, they have also followed China Mobile's lead in deploying distributed radio systems in select venues. For example, both China Telecom and China Unicom have deployed Ericsson's Radio Dot product in hundreds of commercial buildings to provide robust in-building mobile service coverage. As a predominantly fixed operator, China Telecom in particular has been thoughtful in integrating residential femtocells and enterprise-focused small cells in its overall mobile infrastructure plan. With much smaller mobile businesses in terms of subscribers and infrastructure footprints however, China Telecom and Unicom have struggled to compete effectively with China Mobile. If repeated rumors of a merger of the two were to happen, it is possible for the small cell investments to tick up as disparate macro investments can be pooled together, and additional capital expenditure can be allocated for small cell investments in strategic venues. However, we believe this is a remote probability and have not factored this scenario in our forecast.



Source: Mobile Experts

Chart 8: Small Cell Forecast, China, 2016-2022

The enterprise small cell market is almost non-existent in China as it is customary for operators to take the lead in in-building wireless projects. The Chinese operators take primary responsibility for providing mobile coverage everywhere – both outdoors and indoors. Hence, we do not forecast any meaningful deployments of enterprise small cells in China. Rather, we account for enterprise-targeted small cells for China market as a part of Carrier Indoor small cells in our forecast. In fact, the majority of 'Carrier Indoor' units for China are DRS radio units. Moreover, a small portion of 'Carrier Outdoor' units for China are also DRS radio units deployed in outdoor applications.

With ample fiber infrastructure footprint in China, we expect Centralized RAN architectures with low power RRH units to be widespread in the region. China Mobile has been guiding towards this CRAN architecture vision especially as it looks towards virtualized RAN in 5G, with a much denser RAN footprint and higher bandwidth requirements on fronthaul and backhaul links to baseband pooling and 'mobile edge computing' remote data centers. Mobile Experts forecasts a significant portion of the 'Carrier Outdoor' units in China to be low power RRH units, especially in urban deployments.

In rural deployments, we expect traditional RAN architecture to be still applicable and cover remote villages. Small numbers of traditional high-power microcells will cover remote villages, but they will dwindle over time as operators streamline towards CRAN architecture with RRH units with fixed, and sometimes wireless, fronthaul/backhaul links.

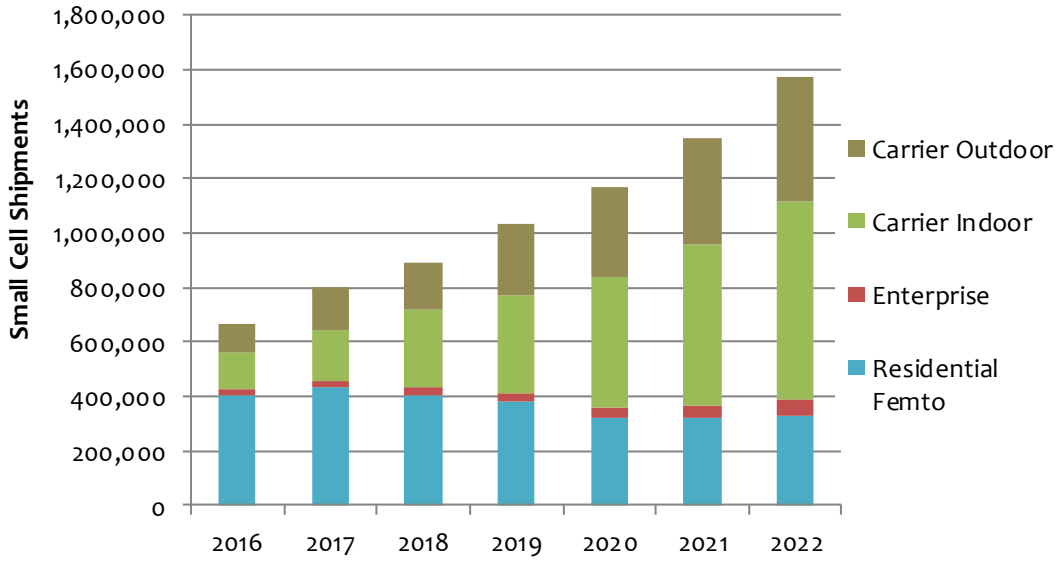
Based on recent RFI activities for residential femtocells at China Mobile, we have boosted our forecast of residential femtocells in 2018 by a meaningful contribution. However, we

do not expect this potential upside in femtocells to outshine the forecasted growth in Carrier Indoor small cell deployments.
China is on track to be the single largest market for carrier-grade small cells as all three operators continue to make meaningful Carrier Indoor and Outdoor small cell investments. With robust fiber infrastructure and commercial venues that are mostly new, carrier small cell deployments for both indoor and outdoor applications seem much easier for the operators in China relative to their peers in North America and Europe who have fragmented ecosystem of regulations and infrastructure footprints.

Asia Pacific (excluding China)

While Korea and Japan have traditionally driven the small cell market in the APAC region, India has emerged as an important market for small cells. Reliance Jio's large deployments of indoor and outdoor units as a part of their coverage and capacity strategy helped to drive small cell volumes in the region. The use of wireless backhaul to fiber-linked macro towers is another differentiating aspect of Jio's network. While it continues to extend its fiber footprint, some facilities are not yet connected via fiber. Unlike in developed markets where small cells are largely viewed as a capacity solution, Jio's perspective of small cell is both for coverage and capacity, and both indoor and outdoor small cells that Jio has deployed reflect this view. Small cell units deployed at Jio support relatively higher user capacity and high output power to extend coverage.

For 2017, Mobile Experts predicts continued growth of small cell units as Jio has formally launched a second phase of LTE network deployment. For India alone, Mobile Experts predicts about 200K carrier indoor units and tens of thousands of residential femtocells.



Source: Mobile Experts

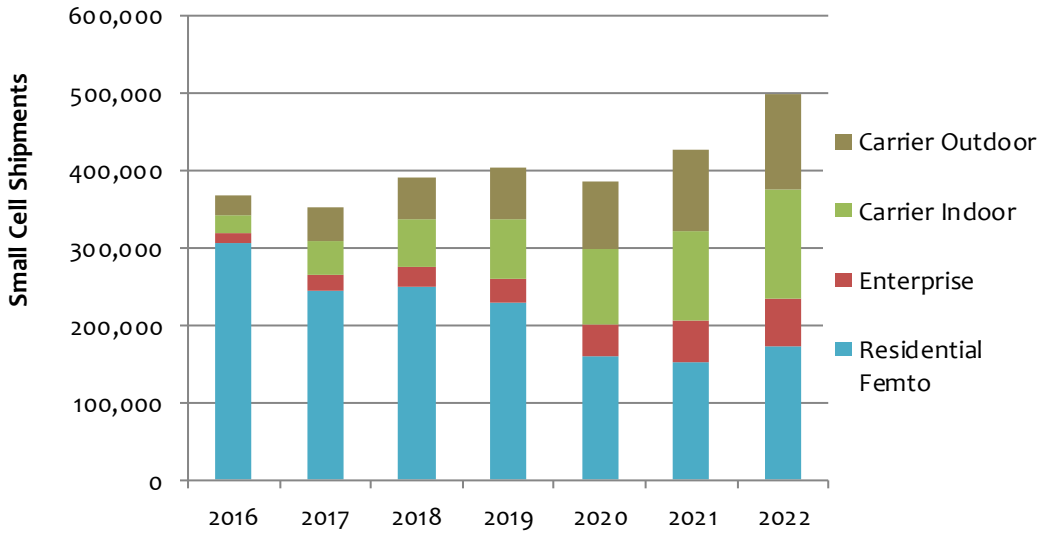
Chart 9: Small Cell Forecast, APAC, 2016-2022

Mobile Experts predicts fairly flat residential femtocell market in APAC as operators are cautious about overusing femtocells that are uncoordinated with the macro layer. While Softbank continues to support femtocells as it has worked out internal processes to manage femtocell-macro coordination, the residential femtocell market in APAC has largely stalled. Moreover, Mobile Experts predicts that the market will shift from residential femtocells to carrier deployed indoor and outdoor small cells over time.

For the rest of APAC region, especially in Southeast Asia, Huawei's LampSite product make up a large portion of carrier indoor deployments. Huawei's Villa Radio is another success story in South Asia, with 10K units deployed during its first six months, in Bangladesh and Myanmar for basic coverage.

Middle East/Africa

The Middle East region is very diverse. It includes highly urbanized, high-ARPU markets like Dubai and UAE, as well as low-density, low-ARPU markets in Africa. For highly urbanized market like Dubai, Mobile Experts predicts that enterprise small cells will be popular as large tall office buildings will likely be challenged with mobile coverage indoors. Carrier driven indoor deployments will drive volume growth.



Source: Mobile Experts

Chart 10: Small Cell Forecast, MEA, 2016-2022

7 EQUIPMENT OUTLOOK

We generally see steady growth across the different small cell categories that we track (see the *Forecast Model Update* for new small cell categories), except for residential femtocells whose growth peaked some time ago. Over the course of the past year, our quarterly forecasts have changed materially downward as enterprise channel push and a notable small cell program at China Mobile did not materialize as expected. Despite these "headwinds", we see an uptick in small cell market activities in terms of operator commitments and continued investments in small cells to densify mobile networks for capacity augmentation and coverage enhancements for both indoors and outdoors.

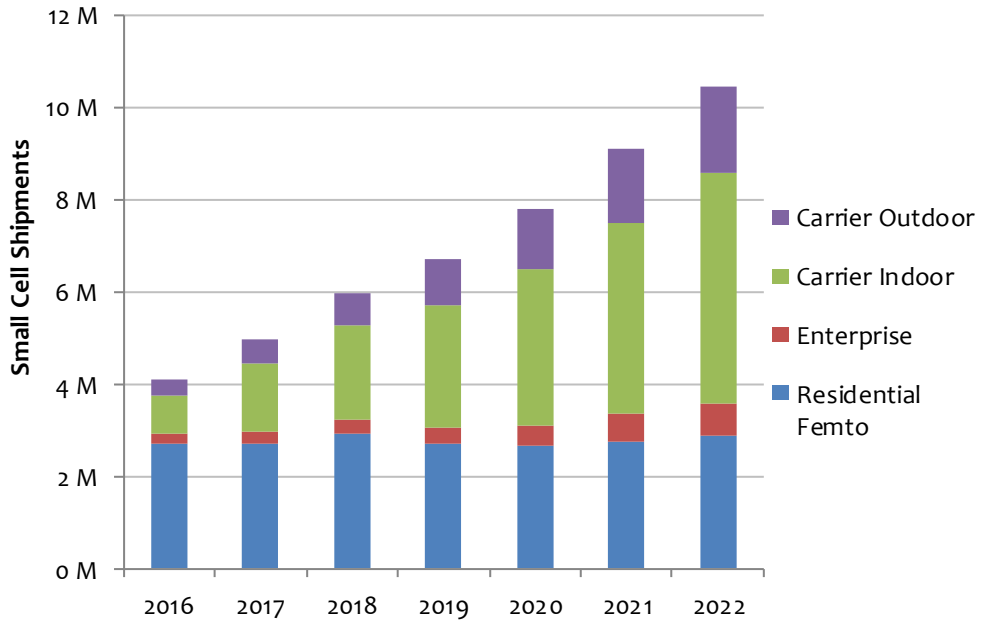
As we look out to the rest of 2017 and near to mid-term outlook, we do not see any macro-level headwinds that will impede small cell growth. As long as mobile data demand keeps up, we expect network operators will continue to expand small cell coverage especially indoors to expand the network footprint. This in turn will drive demand for capacity increase. Increasing radio footprint closer to users will be a continuing network trend as operators employ both network densification and spectrum deployment to increase wireless capacity. LTE radio deployment will also increasingly be undertaken as a first step in 5G deployment, with low latency backhaul/fronthaul and a dense grid of small cells.

5G small cell deployment will come to market during the next five years. Below 6 GHz, most 5G requirements will be satisfied with high-power macro infrastructure. Above 20 GHz, "macro" power levels are not yet possible due to physical limitations in semiconductor efficiency, so we expect operators to focus on small cell strategies.

Small Cell Shipment Forecast

Overall small cell shipments are expected to grow steadily from 2016 to 2022 at a 17% annual rate. The Carrier Indoor and Outdoor segments in particular are expected to see healthy growth at over 30% each, as operators increasingly look to direct deployment of small cells to increase traffic density.

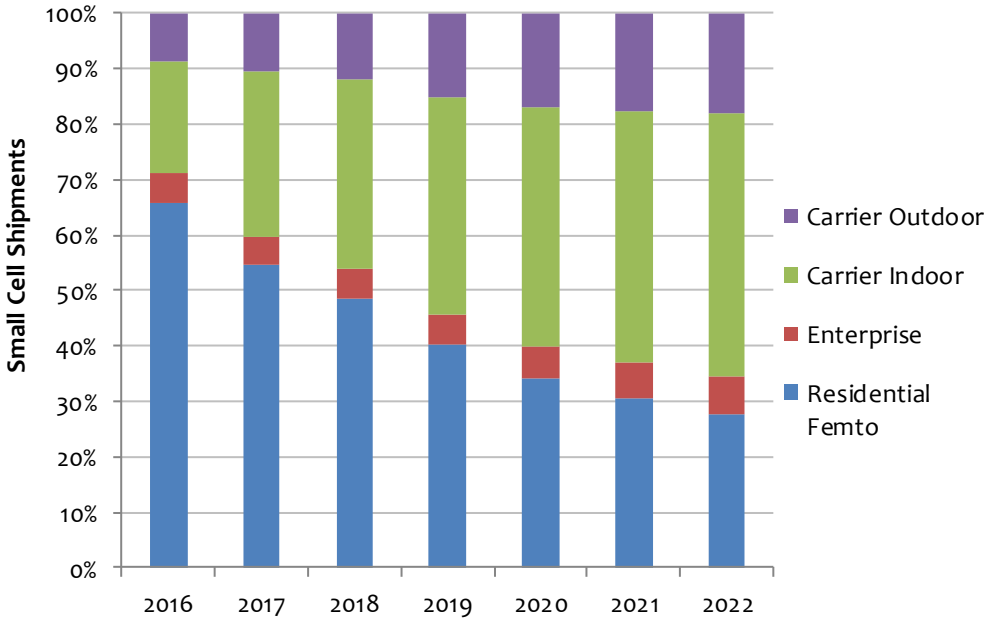
Small cell 'infill' projects are often a logical next step in mobile network projects as operators optimize their RF networks to fill-in coverage 'holes' from initial macro deployments. With initial LTE macro deployments in China and India largely complete, we saw a marked increase in carrier indoor and outdoor deployments in 2016, and 2017 is expected to be another banner year as we observe increasing carrier commitment for small cell deployments in China, APAC and North America.



Source: Mobile Experts

Chart 11: Small Cell Shipment Forecast, by Product Type, 2016-2022

We continue to see signs of non-residential small cells gaining traction in the marketplace. Although residential femtocells dominate annual unit shipment today, it is expected to represent less than 30% of total small cell shipments by 2022.



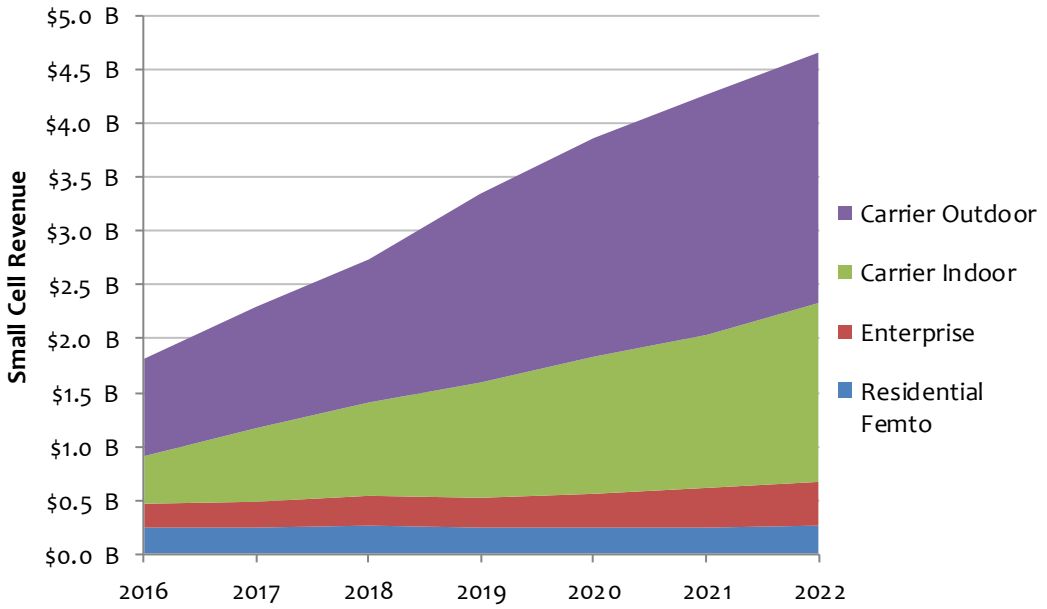
Source: Mobile Experts

Chart 12: Small Cell Shipment Share, by Product Type, 2016-2022

Although we had hoped for a big enterprise small cell shipment in 2016, that did not materialize as Cisco's direct-to-enterprise channel push did not get the necessary approval from key American operators. While we continue to believe that third-party channels to enterprise are necessary to scale the deployment of small cells indoors, the market challenges of lengthy operator approval process and high-margin profit expectations of large enterprise players like Cisco and others are hampering progress in the enterprise segment. Hence, our forecast for the enterprise small cells has been reduced from over 30% in our previous forecast update to about 20%. It is possible for the Carrier Indoor units to meaningfully shift to the Enterprise segment over time as third-party enterprise channels open up.

Small Cell Revenue Forecast

Small cell revenue grew 25% in 2016 year over year, and it is expected to grow at 17% CAGR during our forecast period from 2016 to 2022. While significant shipment volumes come from residential femtocells and carrier indoor units, a bulk of revenue comes from Carrier Outdoor small cells especially high-power (above 5W per antenna) units, which make up between 10-15% of annual Carrier Outdoor shipments.



Source: Mobile Experts

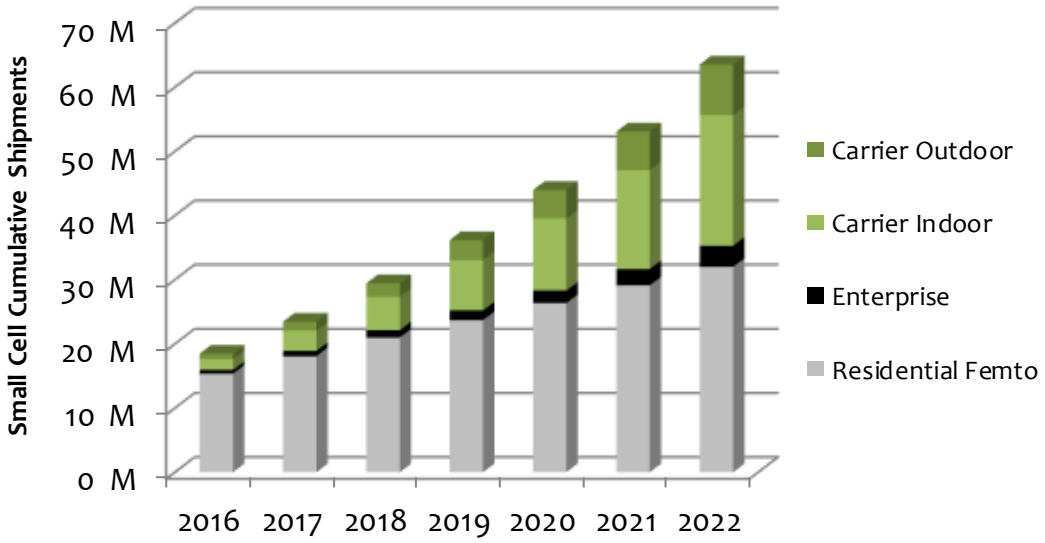
Chart 13: Small Cell Revenue Forecast, 2016-2022

While residential femtocells make up anywhere from about 30% to 66% of total annual small cell shipments, residential revenue contribution is only 6% to 13%. With average selling price less than $100, it is very difficult for femtocell vendors to squeeze out meaningful margins to sustain on-going operations. Not surprisingly, major infrastructure vendors like Ericsson, Huawei, and Nokia mostly focus on the Carrier Outdoor segment;

however, it is imperative for these vendors to also provide broad indoor product portfolios to offer 'one-stop shop' experience for carrier customers. Some enterprise-focused vendors have successfully captured some niche indoor segments, and could capture adjacent segments with higher capacity small cell units that can provide ease of use features like SON and other network management features.

Small Cell Installed Base Forecast

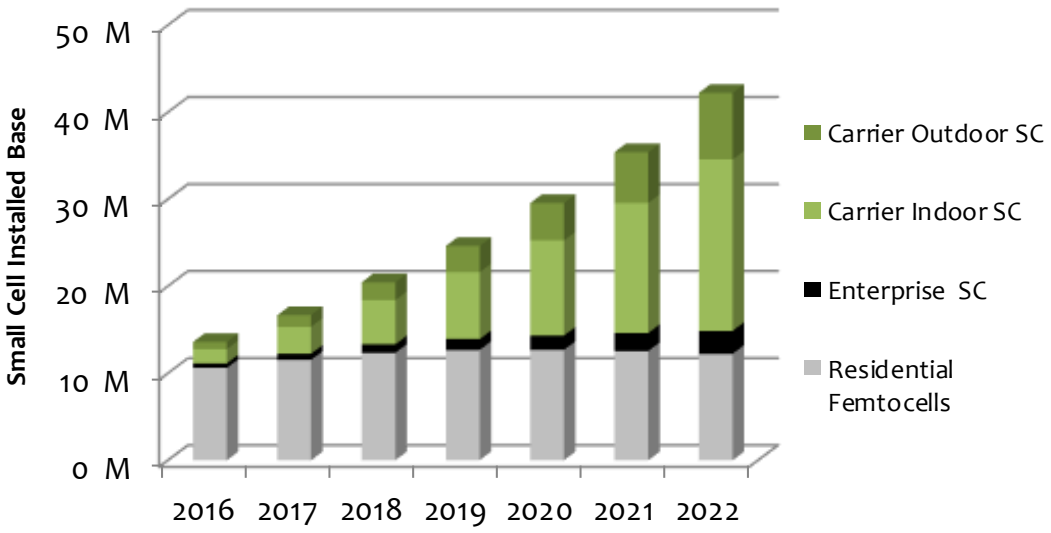
More than 18 million small cells have been shipped to date, and 13 million units are in service. Mobile Experts tracks the shipments in terms of "Cumulative Shipments" (i.e., the total number of small cells sold to customers) and the "Installed Base" (i.e., the number of units that remain in the field).



Source: Mobile Experts

Chart 14: Small Cell Cumulative Shipments, 2016-2022

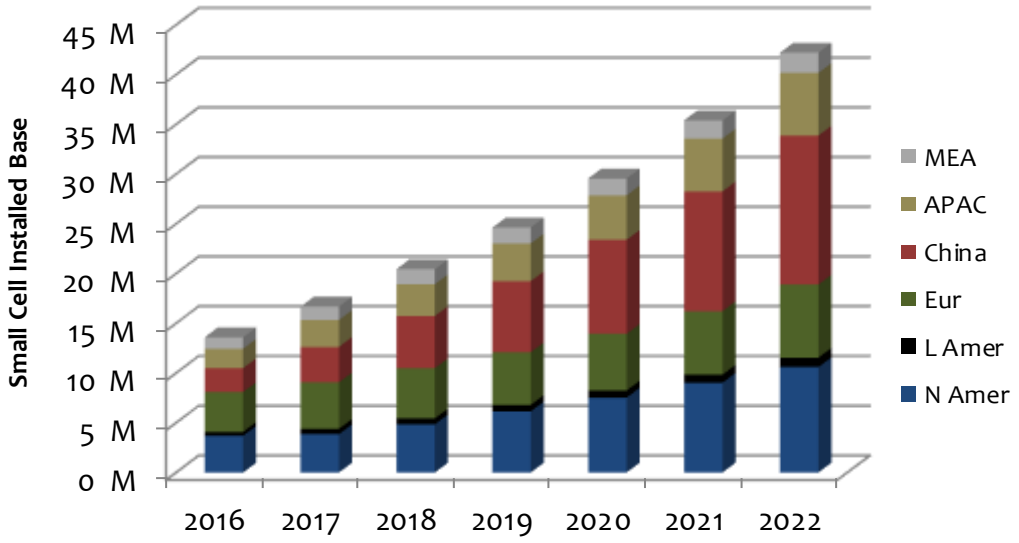
Mobile Experts projects that there is a significant percentage of residential femtocells that are turned off because the end user does not see a benefit, or simply moves to a different location where the unit is no longer needed.



Source: Mobile Experts

Chart 15: Small Cell Installed Base, 2016-2022

While North America and Europe represent regions with large installed base of small cell units, the key regions to watch are North America and China. In China, a large installed base of Carrier Indoor small cells, mostly distributed radio units, are already becoming a platform for value-added enterprise services such indoor positioning and advertising. In the USA, the enterprise segment may truly evolve towards third-party neutral host deployment and management especially with 3.5 GHz CBRS shared spectrum services.



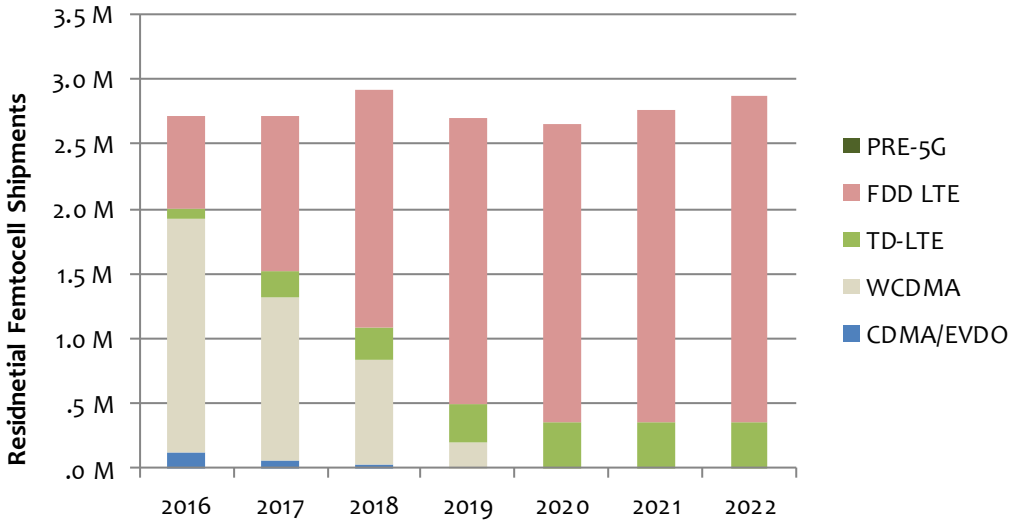
Source: Mobile Experts

Chart 16: Small Cell Installed Base, 2016-2022

Residential Femtocell Forecast

Residential femtocells have reached a peak in recent years as some operators are happy to leverage fixed broadband Wi-Fi access points and voice over Wi-Fi (VoWiFi) technology as a 'good enough' substitute for indoor mobile coverage solution. Instead of subsidizing femtocells, some mobile operators see VoWiFi support on iPhone and Android smartphones as key market development to simply leverage fixed broadband Wi-Fi access points as adequate indoor coverage solution. Cost consideration may be a key driver as mobile operators no longer need to subsidize residential femtocells to extend mobile coverage indoors. Although the growth has stalled, the residential femtocell market is expected to ship around 2.5 million units annually worldwide.

As operators continue to leverage newer air interface technologies to derive more bits per second per Hz (bps/Hz), dual mode 3G/LTE femtocells will increasingly be dominated with FDD LTE units as North American and European regions which have historically dominated residential femtocell market primarily leverage FDD LTE technology. 3G and CDMA units are expected to diminish over the next couple of years as TD-LTE units employed in China and APAC are expected to grow in share.

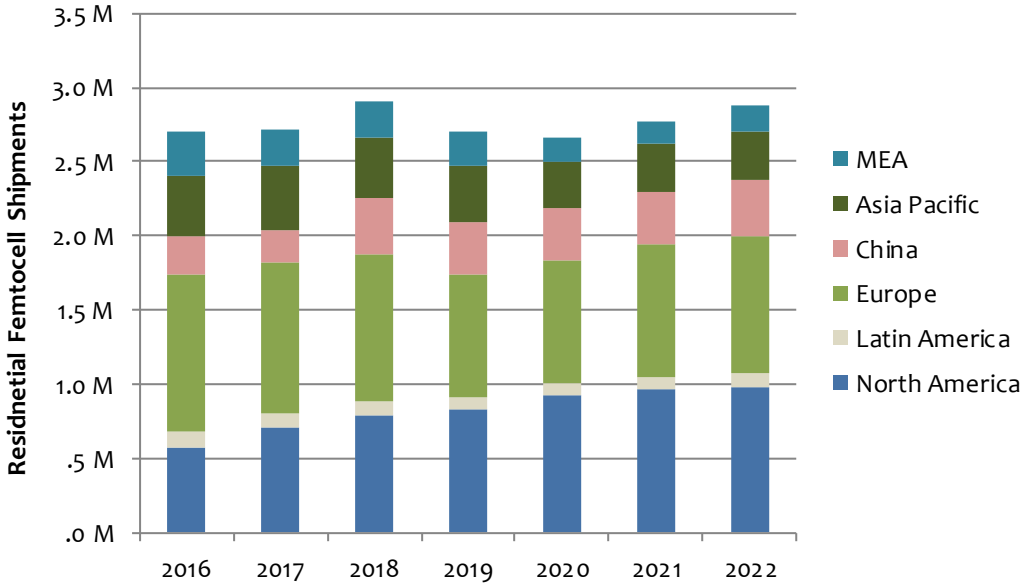


Source: Mobile Experts

Chart 17: Residential Femtocell Shipment Forecast, by Air Interface, 2016-2022

The residential femtocell market is dominated by North America and Europe, as some Tier 1 operators (like T-Mobile USA) are keen to deploy VoLTE as quickly as possible so that they can refarm 3G spectrum for LTE. Also, Verizon, whose licensed spectrum holding per subscriber base is relatively weaker than its competition, seems eager to seed the market with LTE femtocells to expand its mobile coverage indoors. Moreover, with a recent FCC approval for LTE-U/LAA deployment, T-Mobile and Verizon are expected to deploy LTE-U,

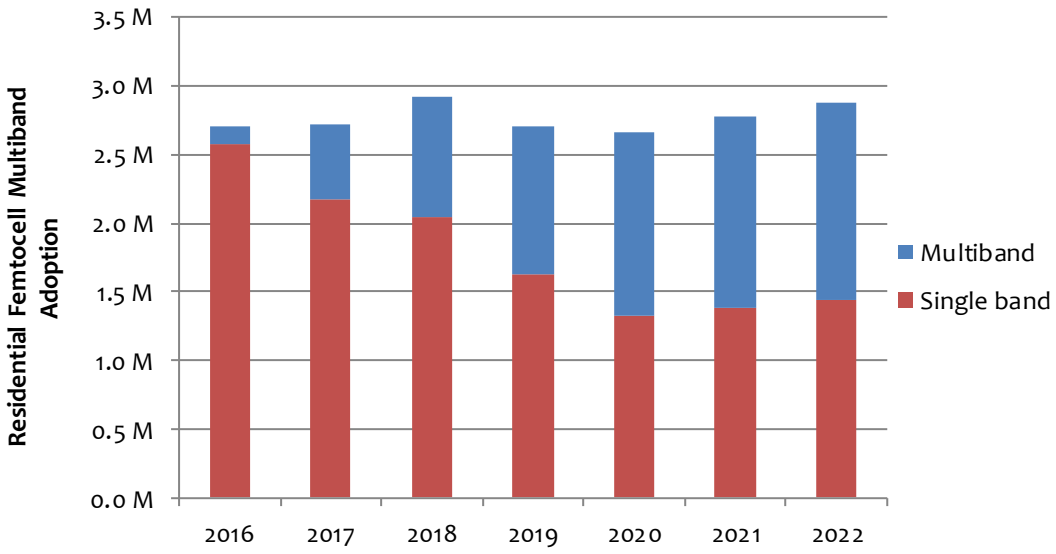
and eventually upgraded to LAA, in certain indoor and outdoor deployments to harness unlicensed spectrum along with Carrier Aggregation feature embedded in LTE-U/LAA to provide higher speed and throughput capacity services. While we do not foresee active deployment of LTE-U/LAA in residential femtocells, mainly due to higher capex cost, the possibility is there. We do account for a minimal upside of this scenario in our residential femtocell forecast, providing an uptick in 2018.



Source: Mobile Experts

Chart 18: Residential Femtocell Shipment Forecast, by Region, 2016-2022

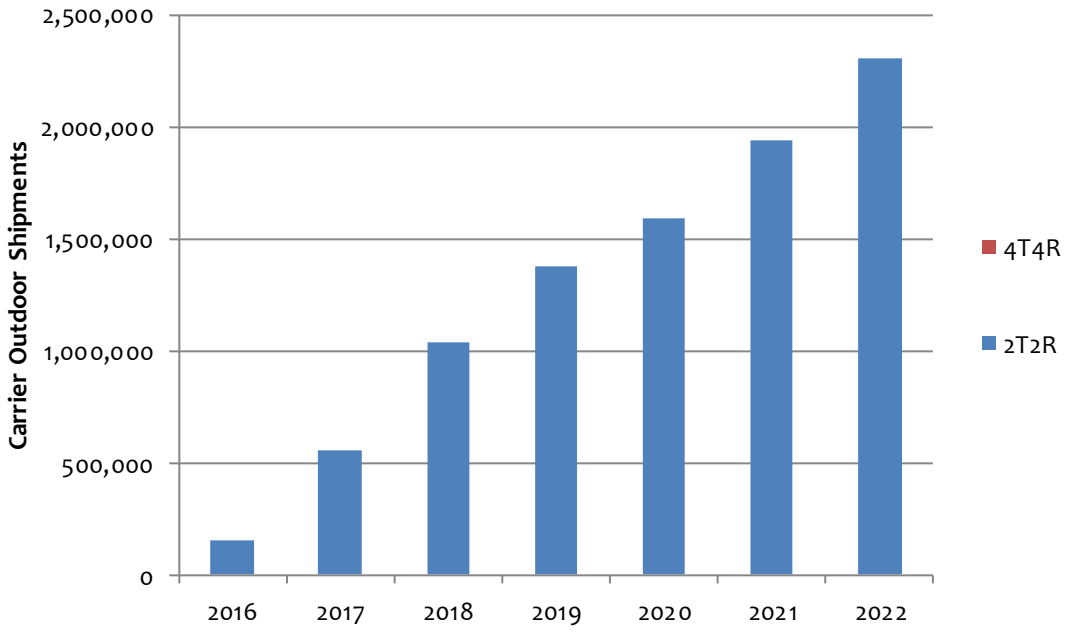
Residential femtocells are becoming more powerful with increased LTE capacity, some even up to handling 64 users with 3G/LTE dual band support. While a majority of residential femtocells shipped today are single-band devices, we expect an increasing number of new residential femtocells to support multiband carriers with two RF carriers for 3G + LTE configuration or two LTE carriers to possibly take advantage of carrier aggregation.



Source: Mobile Experts

Chart 19: Residential Femtocell Shipment Forecast, by Multiband Type, 2016-2022

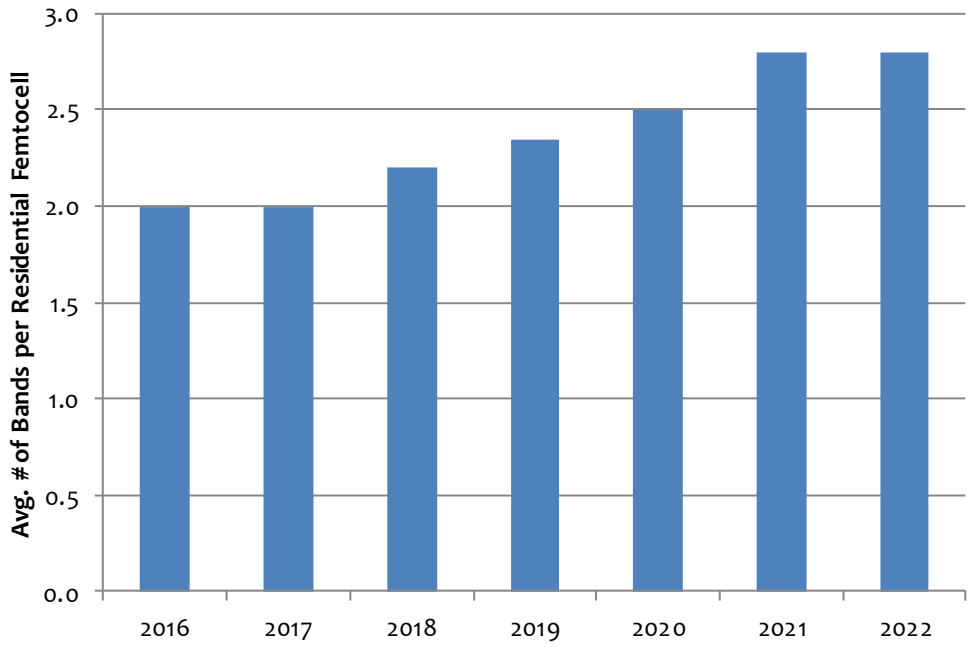
During our forecast period, we expect an increasing number of residential femtocells to support two RF carrier (2Tx / 2Rx) configuration with internal omni-directional antenna for easy self-install. With cost constraint, we do not expect residential femtocells to adopt higher RF carrier configurations such as 4Tx / 4Rx, which will more common for higher-priced outdoor units.



Source: Mobile Experts

Chart 20: Residential Femtocell Shipment Forecast, by Antenna Configuration, 2016-2022

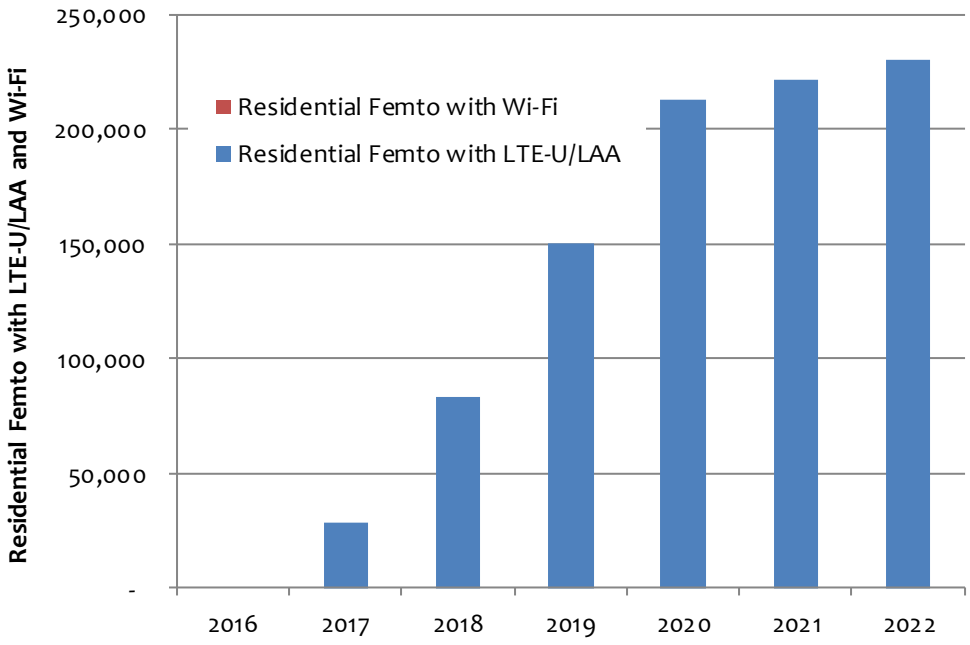
The average number of bands per residential femtocells will be around 2. We expect this figure to slightly increase in 2019 time period as some leading operators may look to support additional bands to take advantage of unlicensed and shared spectrum bands with carrier aggregation to support higher speeds. The weighted average of these 'high capacity' femtocells will move the average number of bands higher.



Source: Mobile Experts

Chart 21: Avg. # of Bands per Residential Femtocell Unit, 2016-2022

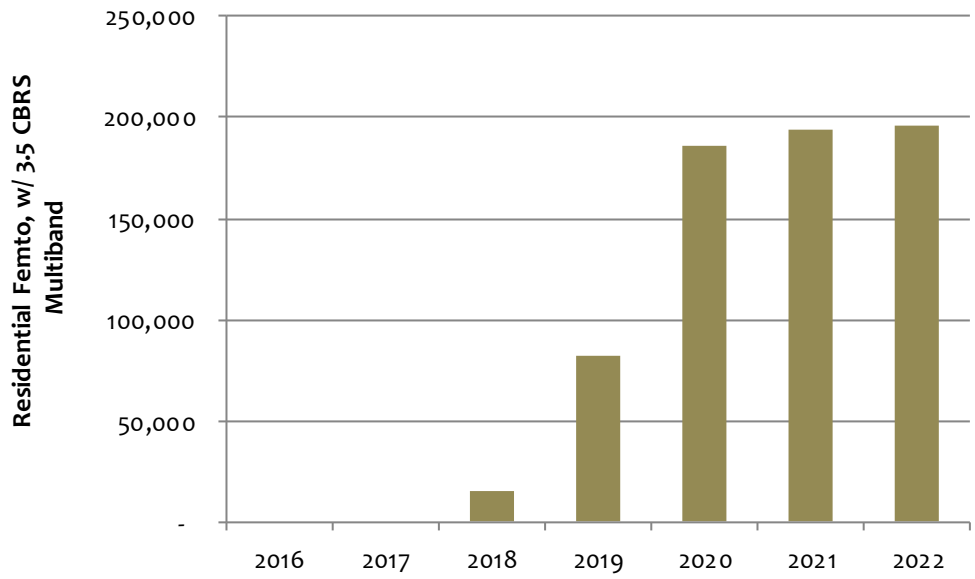
With LTE-U/LAA and Wi-Fi, mobile operators can take advantage of 5 GHz unlicensed spectrum band to provide additional capacity. With low price-point targets for residential femtocells, we do not expect significant adoption of these technologies on residential femtocells. We expect low adoption of Wi-Fi integrated residential femtocells. Consumer Wi-Fi penetration is already high in most developed markets with high fixed broadband penetration; hence, integrating Wi-Fi onto residential femtocells is redundant in most cases. The LTE-U/LAA adoption on residential femtocells is expected to be minimal, reaching less than 10% of global residential femtocell shipments annually. We expect most operators looking to leverage LTE-U/LAA will target Carrier Indoor and Outdoor small cells instead to avoid high contention areas within consumer homes to franchise venues where operators have some level of control in terms of where and how unlicensed access points can be leveraged in a given location.



Source: Mobile Experts

Chart 22: Residential Femtocell Shipment Forecast, with LTE-U/LAA and Wi-Fi, 2016-2022

The adoption of 3.5 GHz CBRS shared spectrum is expected to ramp in 2018 as the ecosystem of shared spectrum access systems including SAS and ESC come online. While direct mobile operator deployment of CBRS base stations is still too early to tell, there is a possibility of cable operators to leverage its dominant fixed broadband market share to enable 3.5 GHz CBRS service via broadband CPE gateways. Our current forecast caps the attach rate at 20% in the US market. Depending on strategic intent and pace of cable operators' wireless entry and iOS and Android device ecosystem support, our forecast can potentially move up significantly, or it can go 'flatline' if a sustainable business model is not achieved in time.



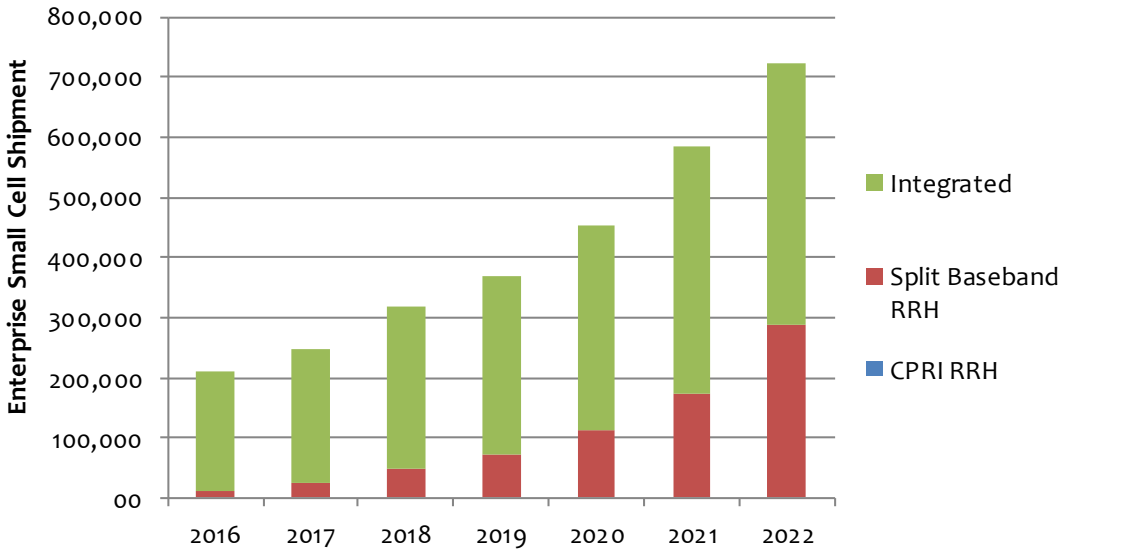
Source: Mobile Experts

Chart 23: Residential Femtocell Shipment Forecast, with 3.5 GHz CBRS Multiband, 2016-2022

Enterprise Small Cell Forecast

While the 'direct-to-enterprise' model did not materialize in 2016 as Cisco expected, the enterprise market is growing steadily. Pent-up demand from enterprises is strong everywhere. Enterprise-focused OEM suppliers are building sales channel partnerships and working with key Tier 1 operators to push enterprise small cells directly with large enterprises.

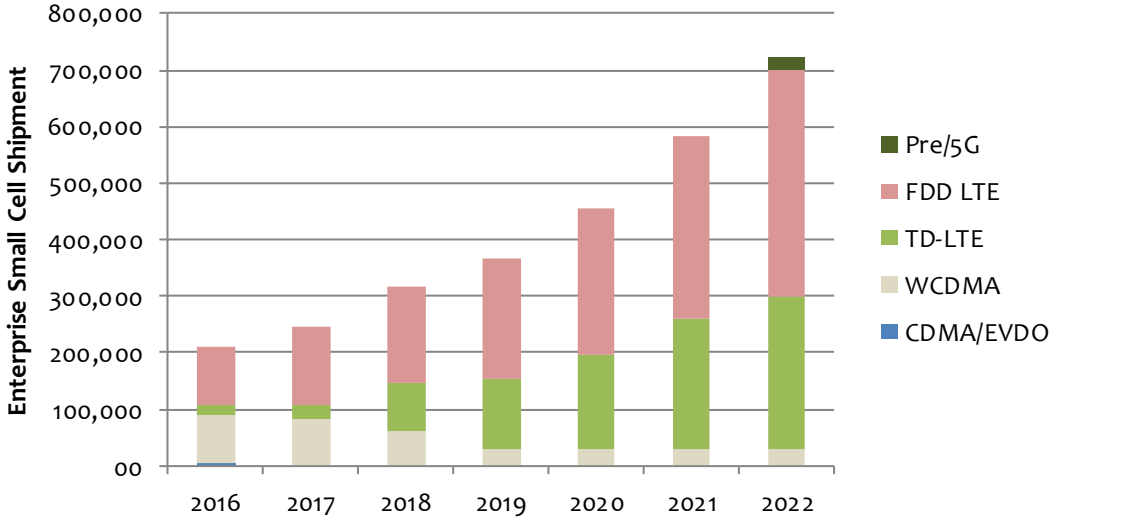
Enterprise small cells are mostly integrated units with baseband and radio functions housed in a common enclosure for quick and easy installation by IT folks. Small cells need to look and connect (via Ethernet cabling) like Wi-Fi access points which are well known to enterprise IT staff. As enterprise small cells take on more features and higher throughput capacity, we expect fronthaul/backhaul bandwidth requirements to continue to go up. To overcome this challenge, we expect a growing number of enterprise small cells to adopt 'split baseband' RRH architecture where baseband processing is centralized while radio units are distributed.



Source: Mobile Experts

Chart 24: Enterprise Small Cell Shipment Forecast, by Fronthaul/Backhaul, 2016-2022

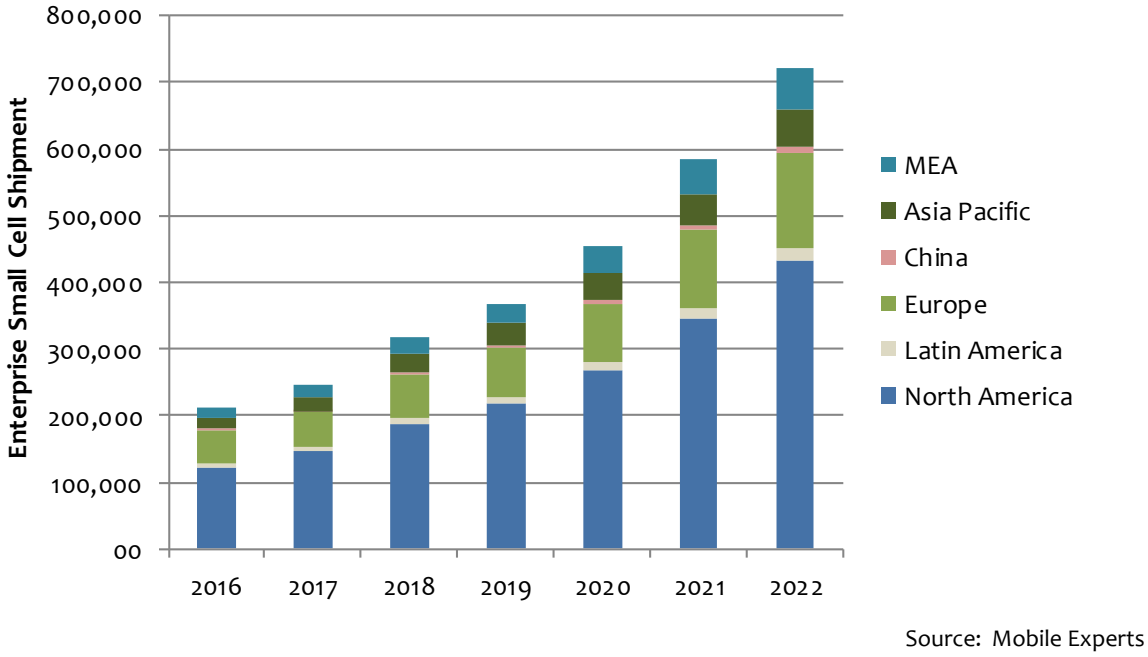
Enterprise small cell adoption has historically been in North America and Europe, hence, WCDMA and FDD LTE have been most popular deployments to date. As small cell deployments increasingly leverage TD-LTE bands in 2.5 GHz, 3.5 GHz, and other 'mid' bands, we expect TD-LTE to take increasing share of enterprise small cell deployments. We expect TD-LTE enterprise small cells. We expect meaningful 3.5 GHz CBRS and Sprint's 2.5 GHz activities to provide meaningful catalyst for growth. By 2022, we forecast a small portion of enterprise small cell units to be 5G capable.



Source: Mobile Experts

Chart 25: Enterprise Small Cell Shipment Forecast, by Air Interface, 2016-2022

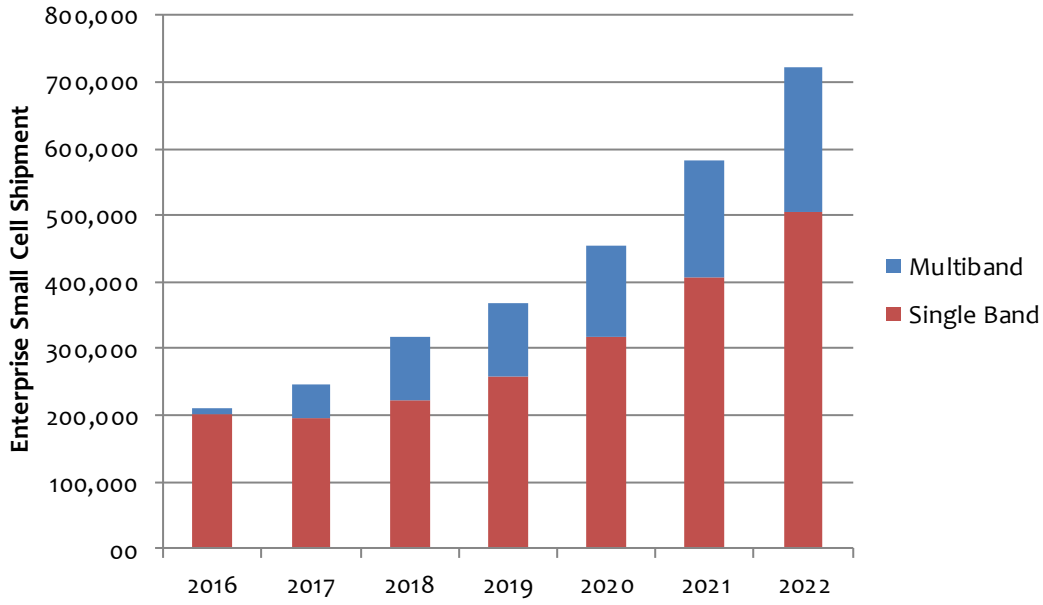
The North American and European regions are expected to continue to lead regional deployment of enterprise small cells as market and cultural norms favor enterprise-led IT/telecom infrastructure investments. Moreover, the key regional operators are hesitant to lead further in-building wireless infrastructure projects beyond the marquee venues like stadiums and large enterprise accounts. The possibility of leveraging 3.5 GHz CBRS infrastructure increases a likelihood of North American dominance of the enterprise small cell market.



Source: Mobile Experts

Chart 26: Enterprise Small Cell Shipment Forecast, by Region, 2016-2022

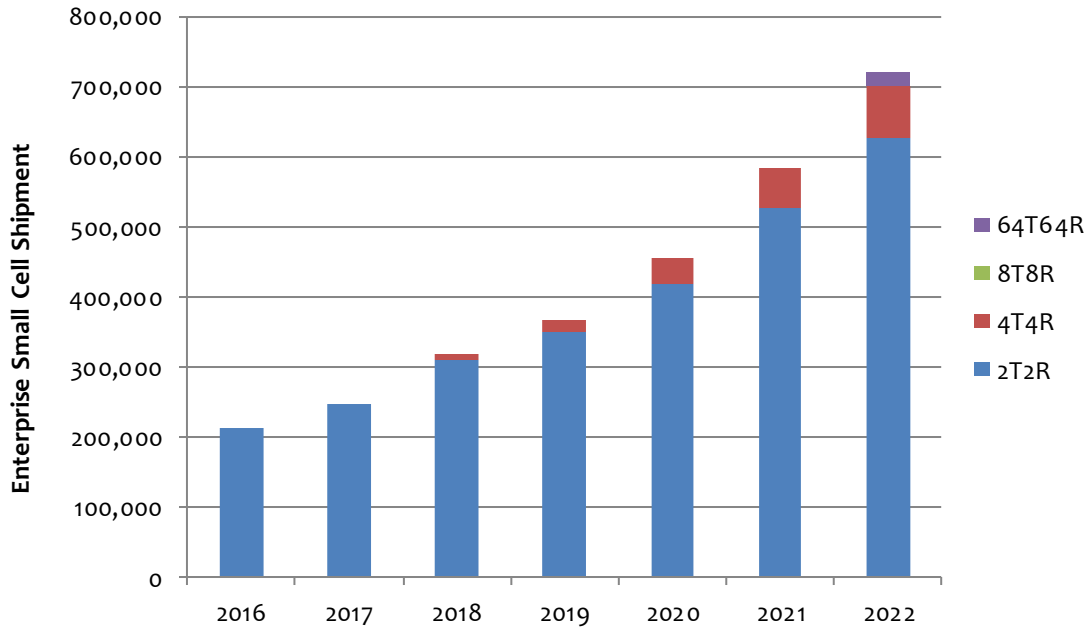
Enterprise small cells are typically higher capacity units with higher output power levels than residential femtocells to provide greater coverage and capacity. As operators deploy additional spectrum bands to increase network capacity, enterprise small cells will follow suit and adopt increasing number of multiband carriers and dual 3G/LTE modes.



Source: Mobile Experts

Chart 27: Enterprise Small Cell Shipment Forecast, by Multiband Type, 2016-2022

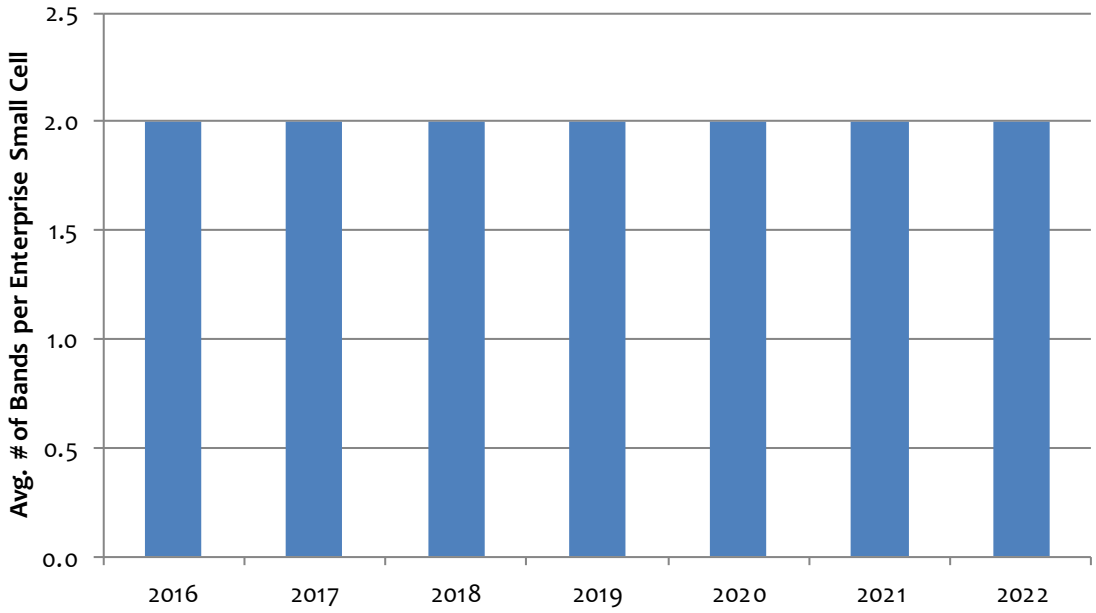
Similar to residential femtocells, most enterprise small cells will support two RF carrier (2Tx / 2Rx) configuration with internal omni-directional antenna for easy self-install. We expect some enterprise small cell units to support 4Tx / 4Rx configuration to take advantage of carrier aggregation. Enterprises will need to support high peak data rates in hundreds of Mbps to keep up-to-date with Wi-Fi speeds. For the 5G capable units at the end of our forecast period, those units will likely support 64Tx / 64 Rx massive MIMO configuration to achieve ultra-high throughput capacity.



Source: Mobile Experts

Chart 28: Enterprise Small Cell Shipment Forecast, by Antenna Configuration, 2016-2022

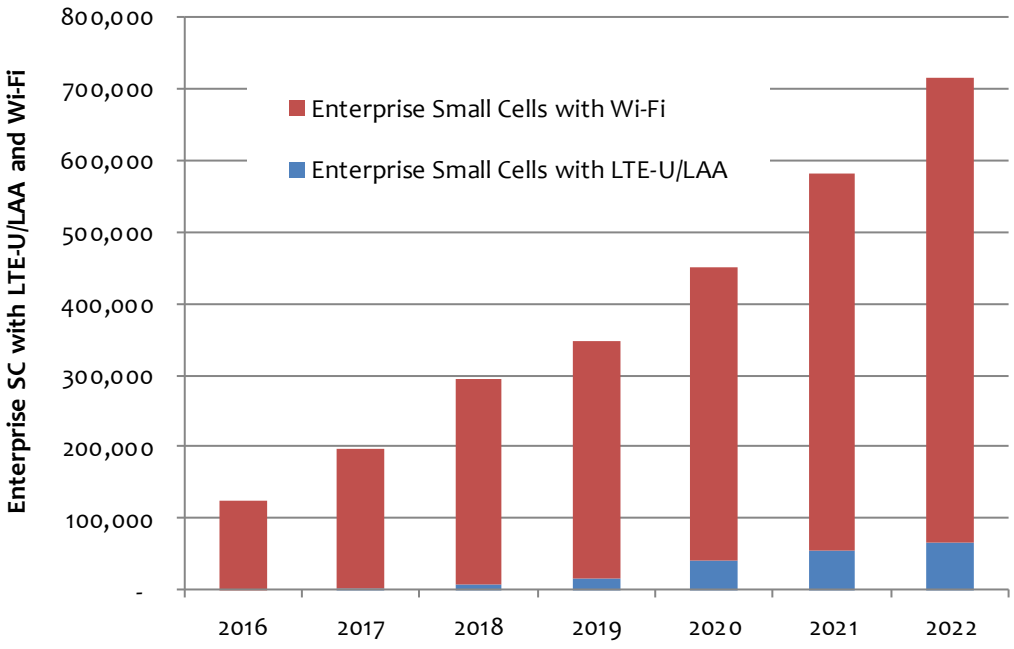
The majority of enterprise small cells today provide dual band support. As operators add additional carriers to take advantage of carrier aggregation for higher capacity throughput and speeds, both integrated and RRH variants will increase additional carrier support. We expect future devices to provide three carrier band support starting in 2019.



Source: Mobile Experts

Chart 29: Avg. # of Bands per Enterprise Small Cell Unit, 2016-2022

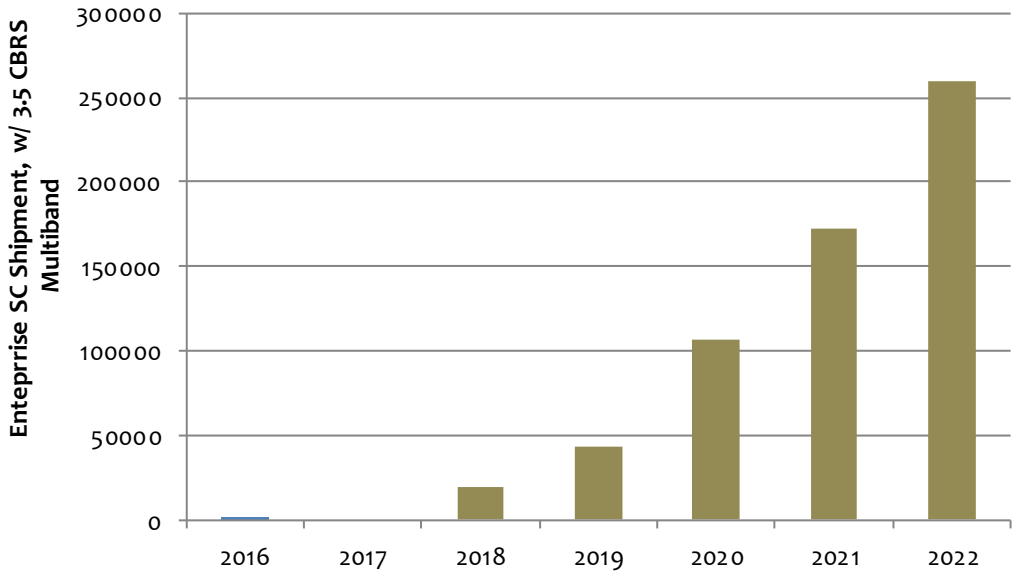
Mobile Experts anticipates more than 90% of enterprise small cells to include Wi-Fi connectivity by 2018, especially as enterprises await the next Wi-Fi upgrade cycle to 802.11ax. During the same time period, Mobile Experts believes that LTE-U/LAA adoption to be scant as enterprise value proposition of adopting LTE-U/LAA is not very clear. Many enterprises have Wi-Fi deployed, and may be wary of deploying LTE-U in the 5 GHz band due to perceived interference concerns. On the other hand, certain enterprises may be incentivized to adopt LTE-U/LAA to enable enterprise applications directly serviced by carriers.



Source: Mobile Experts

Chart 30: Enterprise Small Cell Shipment Forecast, with LTE-U/LAA and Wi-Fi, 2016-2022

The 3.5 GHz CBRS shared spectrum technology can potentially enable neutral host small cell services that enterprises have been yearning for some time. The lightly licensed aspect of CBRS provides cost effective means for new entrants to establish a shared infrastructure (and shared spectrum) model. Of course, this depends on operator and device ecosystem support to operate on this particular band. Android appears onboard (with Google's heavy investment in this ecosystem); however, it is yet unclear whether Apple will provide support for this band in its devices coming to market in 2017 or 2018. Mobile Experts expects more than 60% of enterprise small cells shipped in North America to support CBRS by 2022. Many enterprise small cell vendors have CBRS on their roadmap and in development. We expect trials during the latter half of 2017 and initial volume ramp in 2018.



Source: Mobile Experts

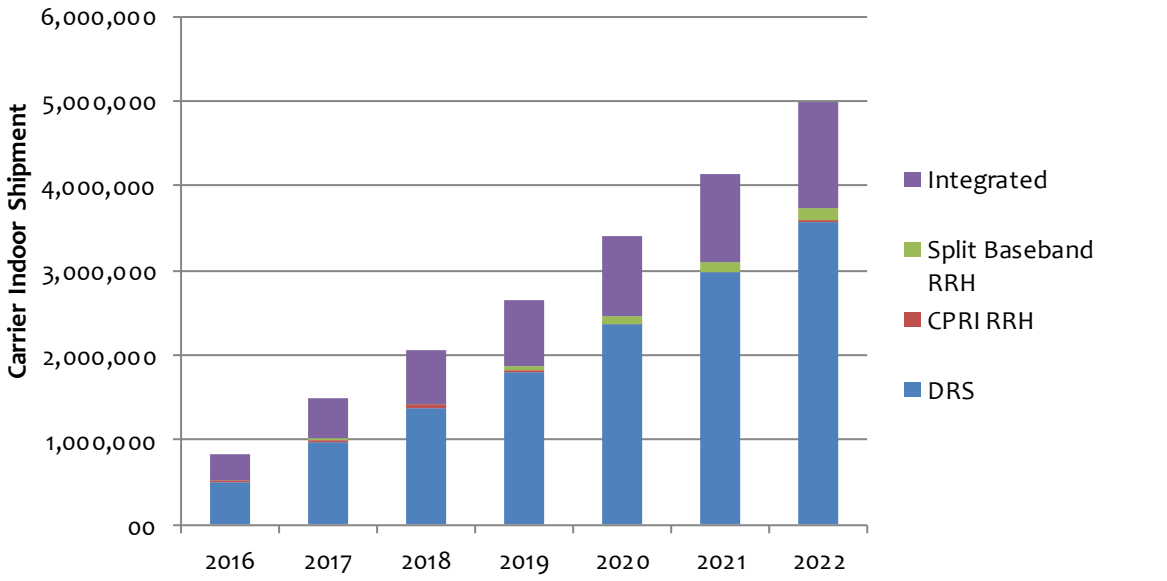
Chart 31: Enterprise Small Cell Shipment Forecast, with 3.5 GHz CBRS Multiband, 2016-2022

Carrier Indoor Forecast

Carriers continue to deploy mobile infrastructure at key indoor venues like office buildings, transportation hubs, and retail malls. China Mobile is a good example. It has been deploying mobile infrastructure at indoor venues to extend its mobile coverage after the massive LTE macro deployment a few years back. While its "Nanocell" project has not yielded millions of enterprise/indoor units for OEM/ODM suppliers, China Mobile has continued to deploy indoor units employing Huawei's LampSite product.

The Carrier Indoor unit shipment grew over 70% year over year in 2016, led by extensive DRS unit shipments in China and APAC, and is expected to grow at a similar rate in 2017 as indoor densification projects in India and China continue. Mobile Experts projects that the Carrier Indoor segment will represent the largest and fastest growing segment, growing at 35% CAGR from 2016 to 2022.

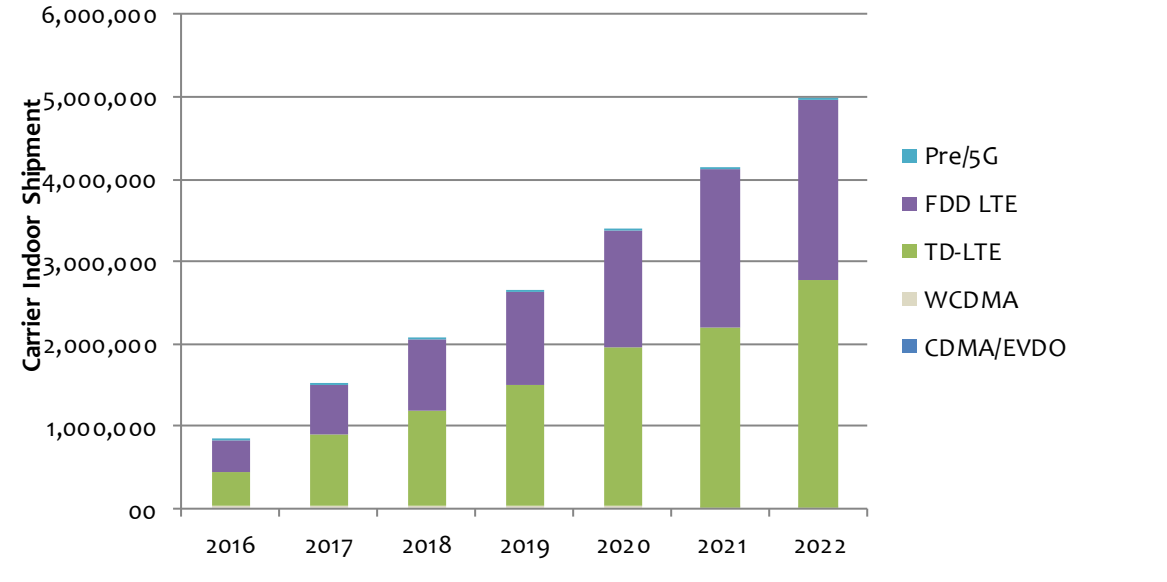
The DRS architecture--including Huawei's LampSite and Ericsson's Radio Dot--has been extremely popular as the DAS-like flexibility in spectrum band deployment and centralized baseband pooling has allowed operators to optimize RF design and resource deployment for specific venue type. In 2016, DRS unit shipments reached over 500K units, making up 60% of the overall Carrier Indoor unit shipments, and Mobile Experts anticipates continued growth of this architecture for operators willing to make mobile infrastructure investments indoors.



Source: Mobile Experts

Chart 32: Carrier Indoor Small Cell Shipment Forecast, by Fronthaul/Backhaul, 2016-2022

With strong growth of Carrier Indoor deployments in China and APAC in 2016 and 2017, TD-LTE is expected to dominate the landscape of Carrier Indoor shipments. With small cell SoC chipset implementations supporting both FDD and TDD LTE operations, incremental cost to support both operations is minimal, and we expect Carrier small cell shipments to support multimode operation.

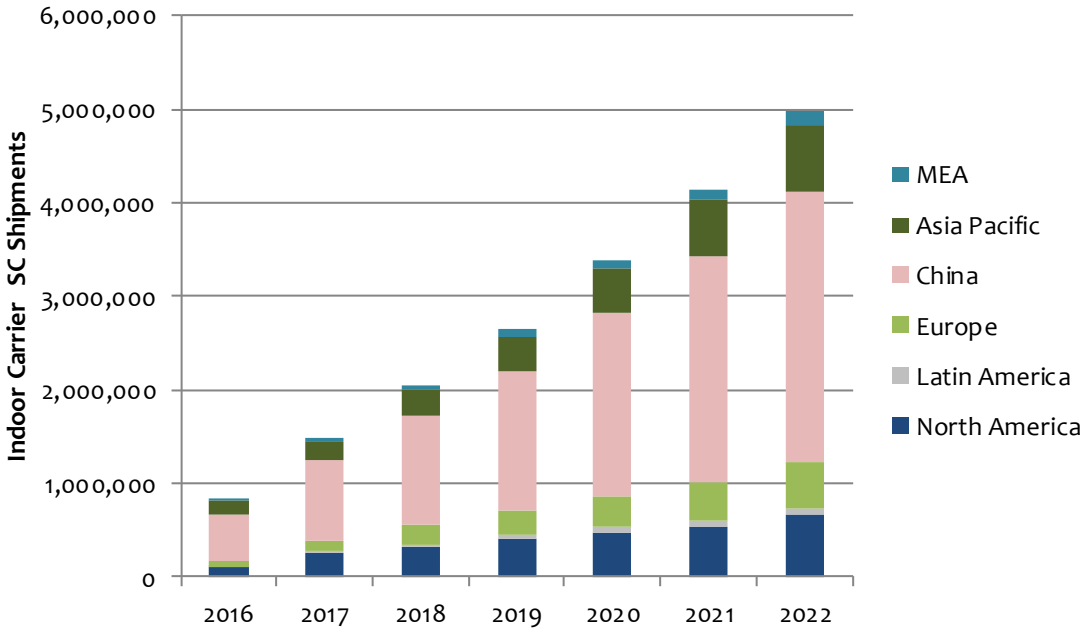


Source: Mobile Experts

Chart 33: Carrier Indoor Small Cell Shipment Forecast, by Air Interface, 2016-2022

With the new model framework to count individual DRS radio units as a single unit versus counting DRS hub as a single unit in previous reporting, regions heavily penetrated with DRS shipments like China and APAC show much higher regional share of Carrier Indoor segments. When the effects of DRS units are removed, the regional share of Carrier Indoor units, comprised of 'Integrated' and 'CPRI and Split Baseband RRH' units, are a bit more balanced with North America and China at similar scale in terms of unit shipments and Europe at about half of North America.

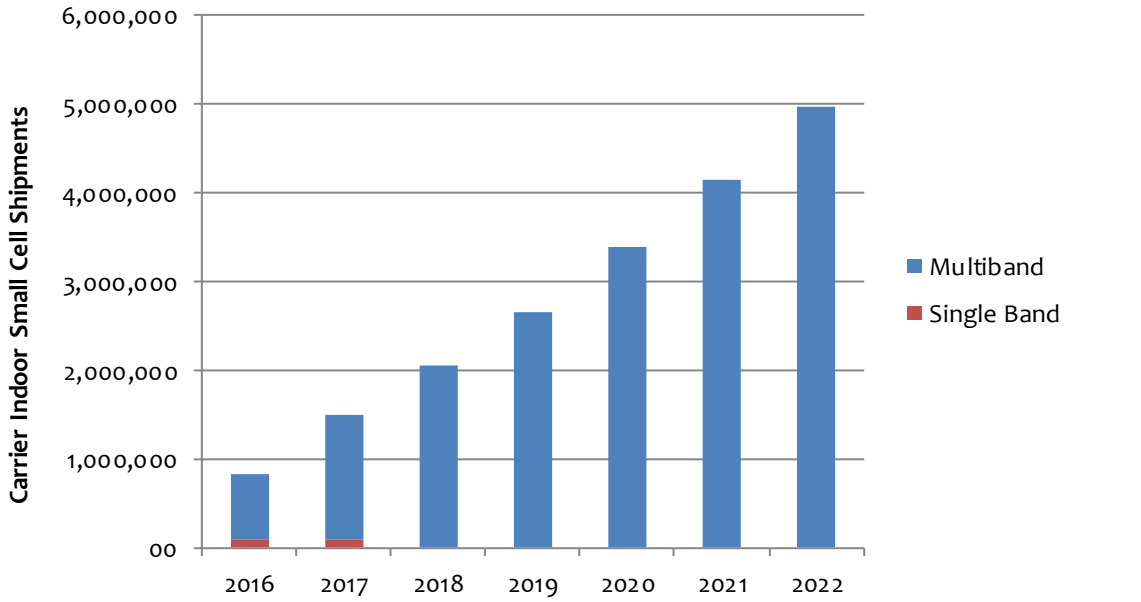
It should be noted that DRS units are similar to DAS remote units except that they are typically deployed for a single operator use versus multi-operator use case for DAS. Mobile Experts tracks a separate *Enterprise Mobile Infrastructure* market forecast that ties together market analysis of Carrier Wi-Fi, DAS and Small Cell segments.



Source: Mobile Experts

Chart 34: Carrier Indoor Small Cell Shipment Forecast, by Region, 2016-2022

Heavy influence of DRS architecture use in the Carrier Indoor segment directly relates to wide adoption of multiband support in Carrier Indoor units. LampSite 2.0 supports three bands, and the next generation LampSite 3.0 supports up to four concurrent bands. As Huawei targets LampSite 3.0 for parts of European and MEA markets where RAN sharing is generally accepted, the shipment figures in Europe is expected to be influenced by a disproportionate increase in shipment figures.

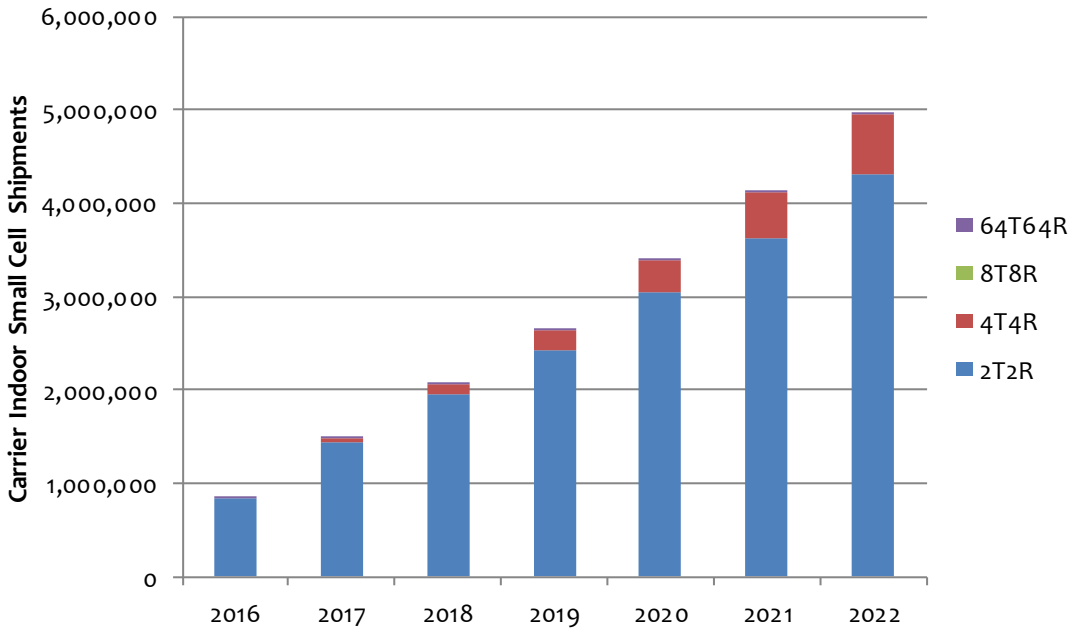


Source: Mobile Experts

Chart 35: Carrier Indoor Small Cell Shipment Forecast, by Multiband Type, 2016-2022

While the majority of Carrier Indoor units are expected to support internal 2Tx / 2Rx antenna configuration on radio units, Mobile Experts predicts that an increasing number of indoor units will adopt 4Tx / 4Rx, especially in larger venue deployments. In the handset market, 4x4 MIMO will become a common feature over the next year.

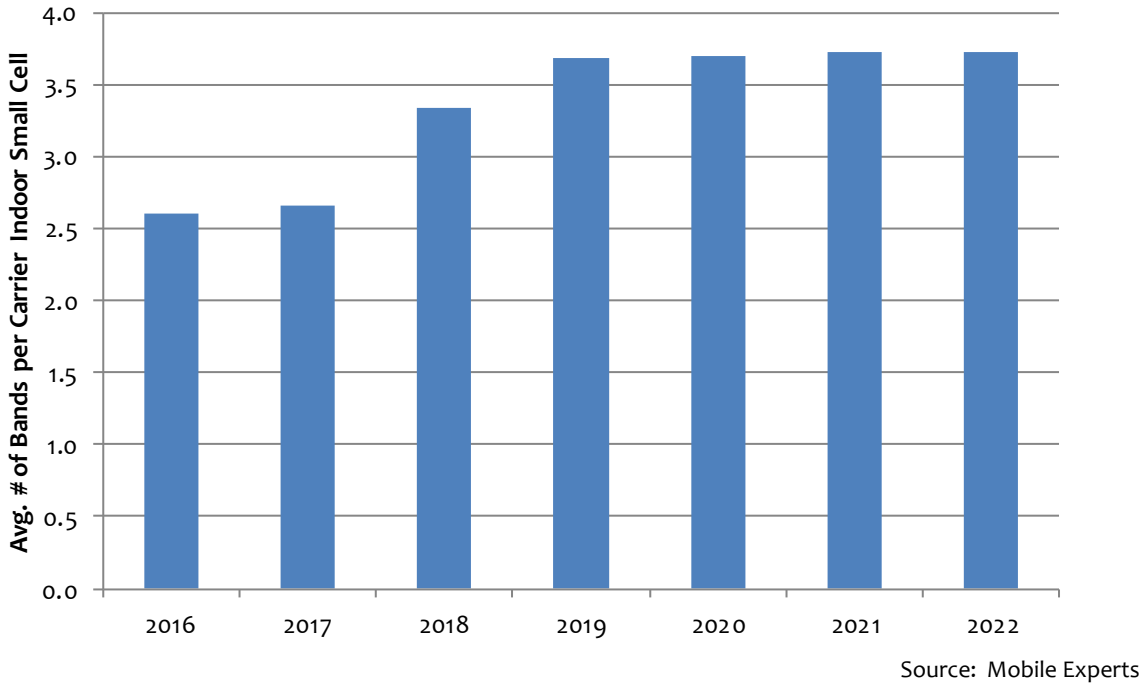
As operators start to trial and deploy 5G low power RRH units leveraging massive MIMO with 64Tx / 64Rx configuration, Mobile Experts expects about 10% of these units will be deployed in indoor settings in dense venue environments. The Carrier Indoor 5G segment will be still very small, reaching about 18K units in 2022.



Source: Mobile Experts

Chart 36: Carrier Indoor Small Cell Shipment Forecast, by Antenna Configuration, 2016-2022

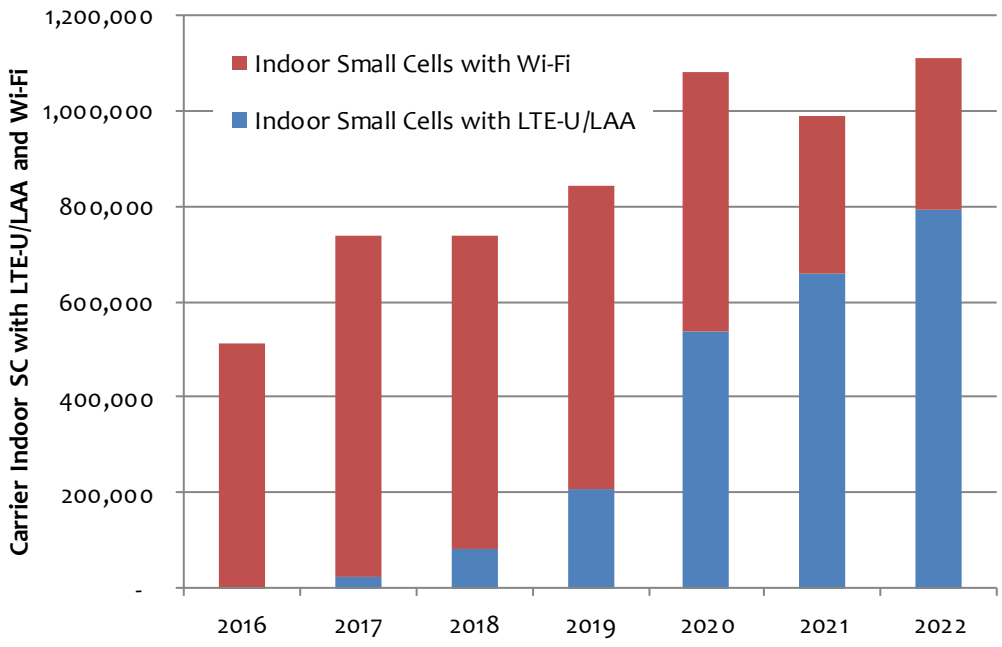
With DRS making up a significant portion of overall Carrier Indoor units, the average number of bands per Carrier Indoor small cell is heavily influenced by the number of bands supported on the leading DRS systems like Huawei's LampSite. LampSite 1.0 began with dual band support, and the current generation, LampSite 2.0, already supports three bands. The next-generation LampSite 3.0, which is expected to launch in second half of 2017, is expected to support four concurrent bands. Overall, the average number of bands per Carrier Indoor unit is expected to increase from about 2.5 today to over 3.5 by 2022.



Source: Mobile Experts

Chart 37: Avg. # of Bands per Carrier Indoor Small Cell Unit, 2016-2022

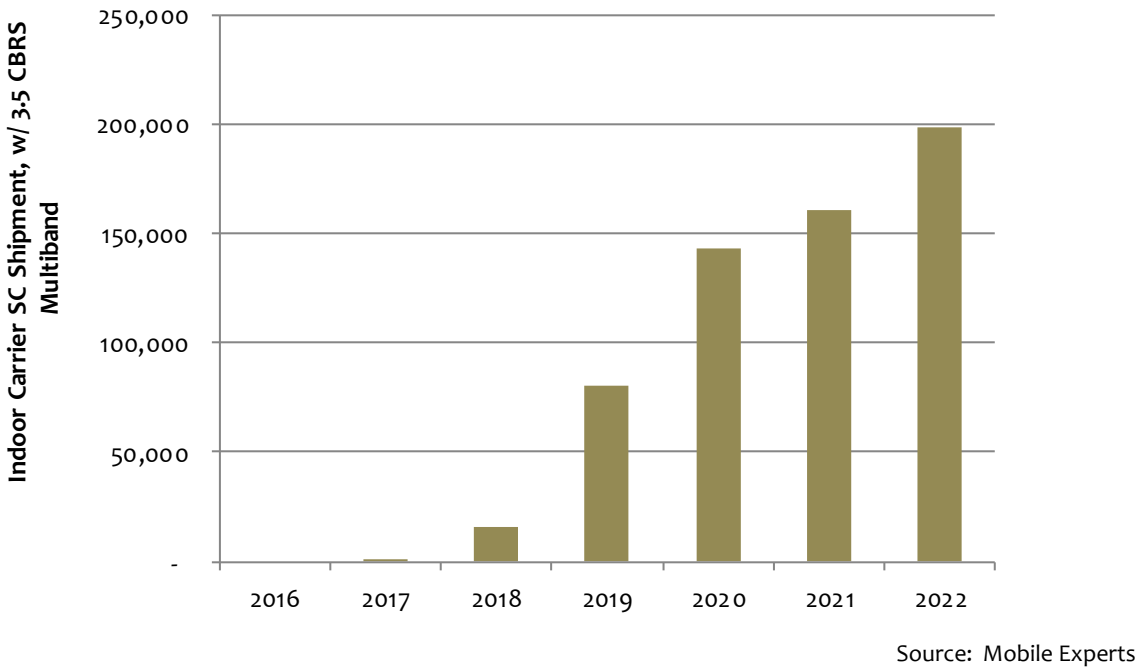
Mobile Experts predicts modest adoption of unlicensed spectrum use in Carrier Indoor context. While the number of Carrier Indoor units incorporating Wi-Fi to use the 5 GHz unlicensed spectrum band is expected to ramp down as operators look to LTE-U/LAA for better use of the unlicensed spectrum, Mobile Experts predicts that the LTE-U/LAA ramp up to be more gradual as operators carefully evaluate unlicensed spectrum contention issues at many of indoor locations. Overall, the combined unlicensed spectrum use through incorporation of Wi-Fi and LTE-U/LAA on Carrier Indoor units is expected to hover around 500K to 1.1M units annually. This constitutes over 20% of total annual Carrier Indoor shipments at the end of our forecast period.



Source: Mobile Experts

Chart 38: Carrier Indoor Small Cell Shipment Forecast, with LTE-U/LAA and Wi-Fi, 2016-2022

While it is still too early to predict mobile operator interest in 3.5 GHz shared spectrum band use via CBRS, Mobile Experts predicts that the potential Carrier Indoor units with CBRS multiband support can reach up to about 500K units by 2022. While we remain optimistic that CBRS can provide benefits to multiple stakeholders including enterprises, neutral host providers and operators, there are many business model challenges that have not been addressed yet. Thus, we have capped the CBRS multiband units at 200K by 2022. First and foremost, Mobile Experts believes that mobile operators need to feel compelled to allow this ecosystem to flourish without possible threat to its business model from potential competitors including cable operators, third-party neutral host players and over-the-top players like Google.



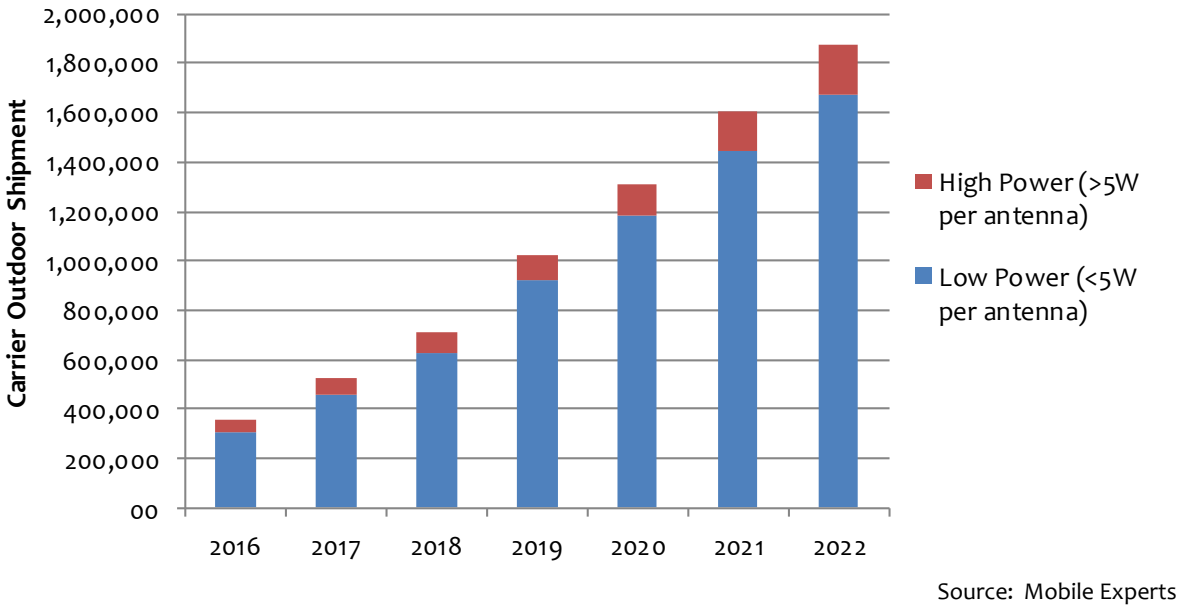
Source: Mobile Experts

Chart 39: Carrier Indoor Small Cell Forecast, with 3.5 GHz CBRS Multiband, 2016-2022

Carrier Outdoor Forecast

As a part of our model update, Mobile Experts now tracks high-power carrier outdoor units (greater than 5W per antenna) typically deployed in rural applications or 'mini macro' deployments in dense urban areas, in place of macro cell deployments. A few key operators drove large numbers of outdoor small cell deployments last year, including Reliance Jio in India, China Mobile and Sprint in the USA. The Carrier Outdoor segment grew 30% year over year in 2016 in unit shipments, largely from activities at Reliance Jio and China Mobile. This year, we are seeing growing outdoor activities at Sprint in addition to the existing outdoor deployments in China and India.

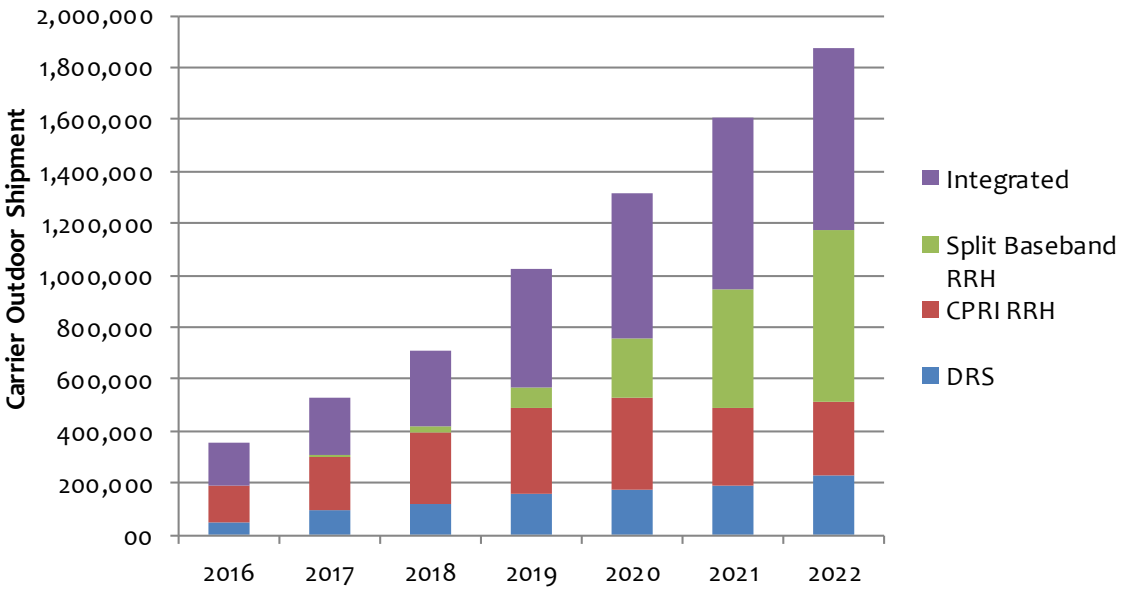
Operators with limited coverage/capacity footprints in dense urban and in rural areas are increasingly leveraging hi-power outdoor units to provide cost-effective mobile coverage and capacity solution to minimize ongoing site lease costs associated with high and escalating site rent. By deploying high-power outdoor units on rooftops and high-rise poles in key right-of -ways, operators like Sprint is looking to lower its network operating expenses. The high-power outdoor units constitute about 10-15% of total Carrier Outdoor units. Several hundred outdoor small cells that Sprint has deployed in NYC are 'mini macro' units that can cover significant coverage area in dense urban locations with up to 20 watts of output power.



Source: Mobile Experts

Chart 40: Carrier Outdoor Small Cell Shipment Forecast, by Power, 2016-2022

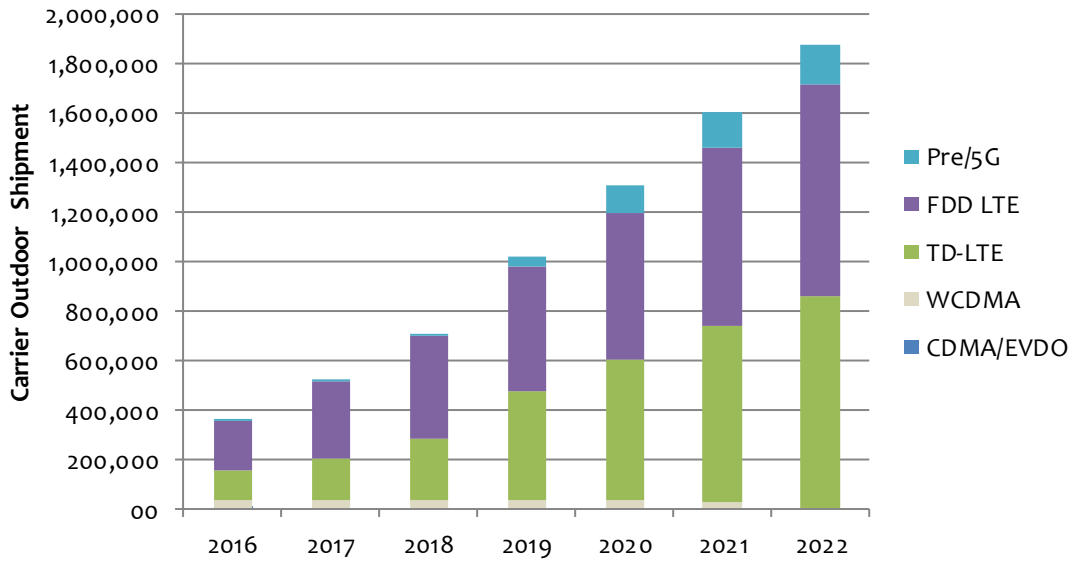
Carrier outdoor applications will increasingly adopt Centralized RAN architecture with low power RRHs to strategically extend mobile coverage and capacity where they are needed. As operators contemplate optimal RAN architecture for 5G services with much higher fronthaul and backhaul bandwidth requirements, Split Baseband RRH will be widely deployed. Meanwhile integrated outdoor small cell units will be deployed in areas where ease of installation is paramount, and interference with the macro layer is less of an issue. While some portion of DRS systems will be deployed in outdoor applications, Mobile Experts expects less than 10% of DRS radio units will be deployed as outdoor units.



Source: Mobile Experts

Chart 41: Carrier Outdoor Small Cell Shipment Forecast, by Fronthaul/Backhaul, 2016-2022

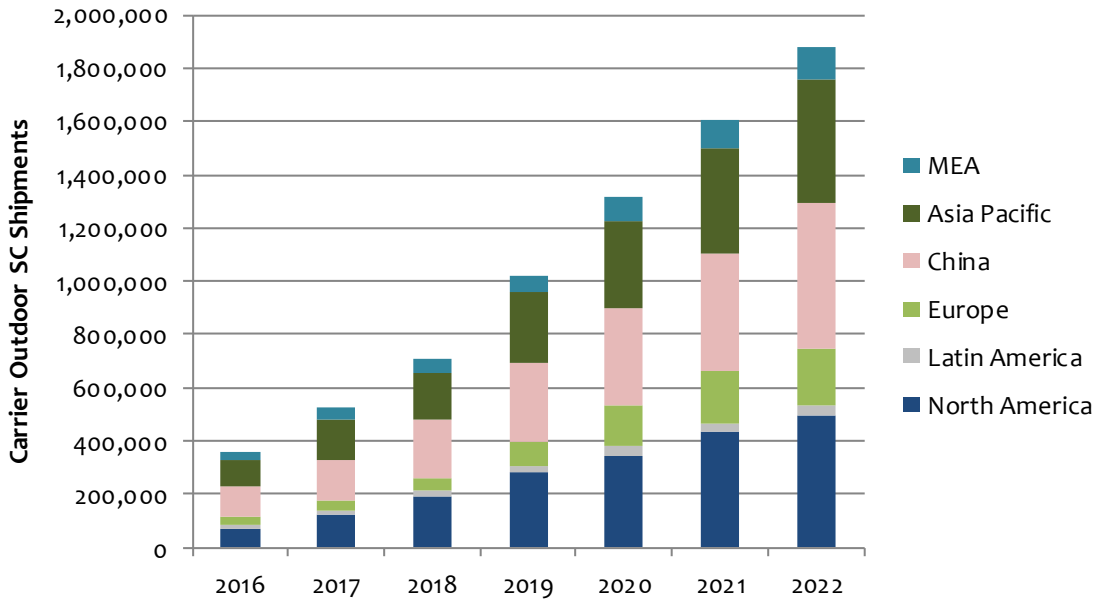
As mobile operators densify their LTE networks, FDD and TD-LTE interfaces are expected to dominate air interface technology share for Carrier Outdoor units. Moreover, 5G outdoor units in the form of low power RRHs is expected to ramp up starting in 2019 as operators begin Pre/5G trials, especially focused on fixed broadband and hotspot mobile applications. By 2022, 5G RRH outdoor units is expected to make up almost 10% of outdoor small cell units… and most of these will be in millimeter wave bands.



Source: Mobile Experts

Chart 42: Carrier Outdoor Small Cell Shipment Forecast, by Air Interface, 2016-2022

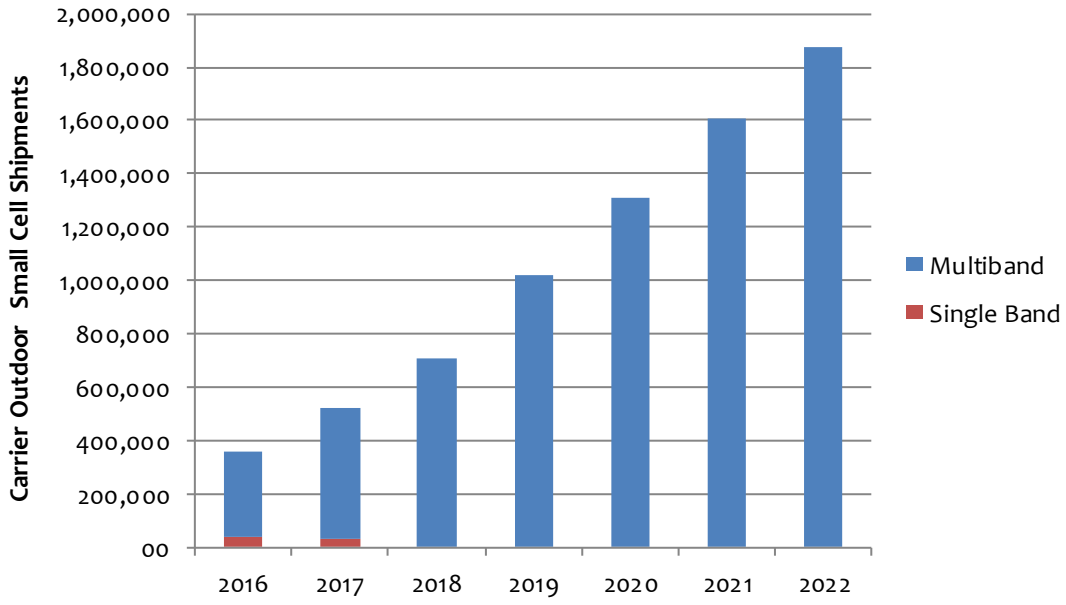
The North American market is expected to be a key segment for carrier outdoor deployments in 2017, as Sprint ramps up outdoor small cell deployments in major markets to bolster its network capacity position. As the smallest of the four mobile operators in the USA, Sprint is looking to leverage outdoor small cells to reduce ongoing operating expenses such as site lease and backhaul. With nothing to lose, Sprint is trying out innovative approaches like placing small cells on top of relatively tall poles along right-of-ways to minimize the number of sites required, and associated lease costs. Where fiber access is limited, Sprint is exploring wireless backhaul options leveraging its spectrum-rich position, including in-band backhaul over the 2.5 GHz band. Outside of the USA, China and India continue to be drive outdoor small cells.



Source: Mobile Experts

Chart 43: Carrier Outdoor Small Cell Shipment Forecast, by Region, 2016-2022

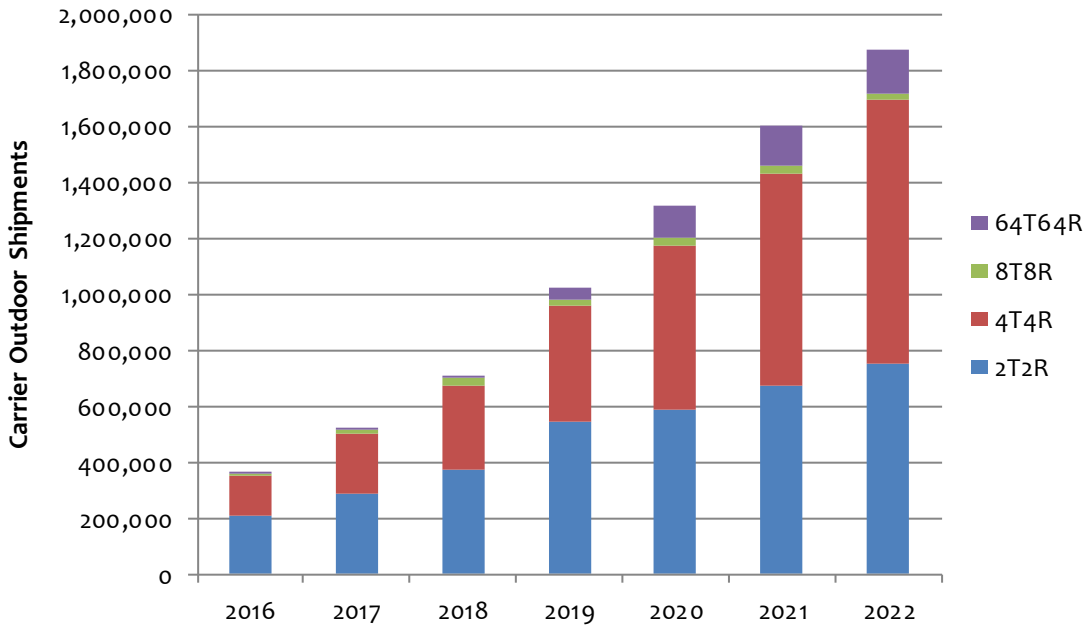
For outdoor applications, multiband support is critically important. A wide variety of 3G and LTE devices will need to be support across multiple frequency bands. Mobile Experts predicts most of carrier outdoor units to support multiband options. Most outdoor products already support multimode, multiband support as this trend will be table stakes in today's market.



Source: Mobile Experts

Chart 44: Carrier Outdoor Small Cell Shipment Forecast, by Multiband Type, 2016-2022

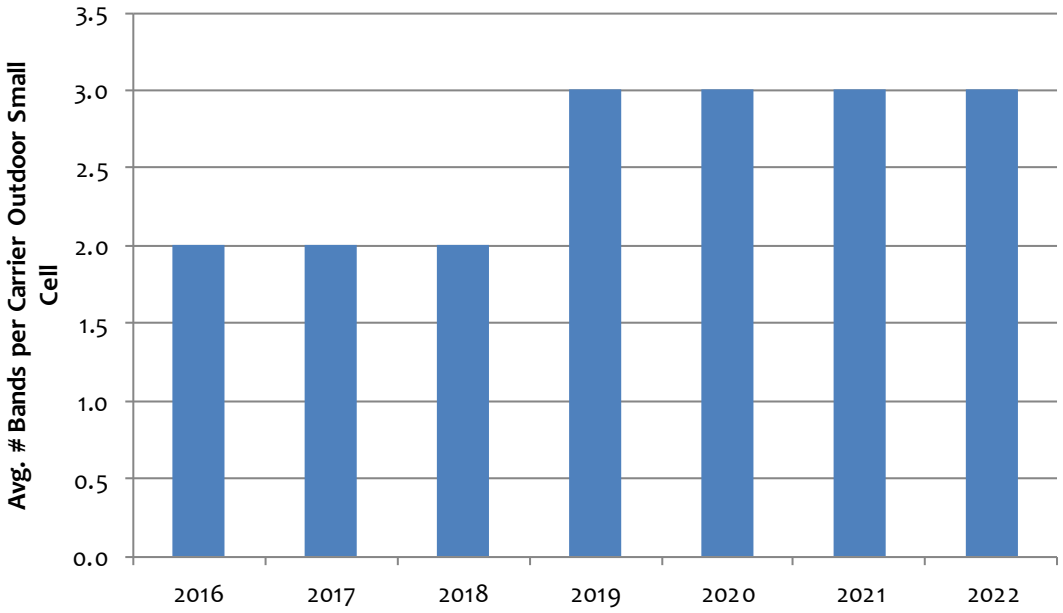
Carrier Outdoor units are highly capable small cells with macro-like features like high RF power, high user capacity, multimode/multiband support, etc. Many outdoor RRH units today support 4Tx / 4Rx, and 8Tx/ 8Rx antenna configuration are also possible in some units. Mobile Experts predicts that a majority of outdoor units will incorporate 4Tx / 4Rx antenna configuration, and 'Pre/5G' units will incorporate 64Tx / 64Rx massive MIMO configuration. With high spectral efficiency that can be achieved with massive MIMO, Mobile Experts predicts that 64Tx / 64Rx configuration will take an increasing share as the semiconductor ecosystem matures.



Source: Mobile Experts

Chart 45: Carrier Outdoor Small Cell Forecast, by Antenna Configuration, 2016-2022

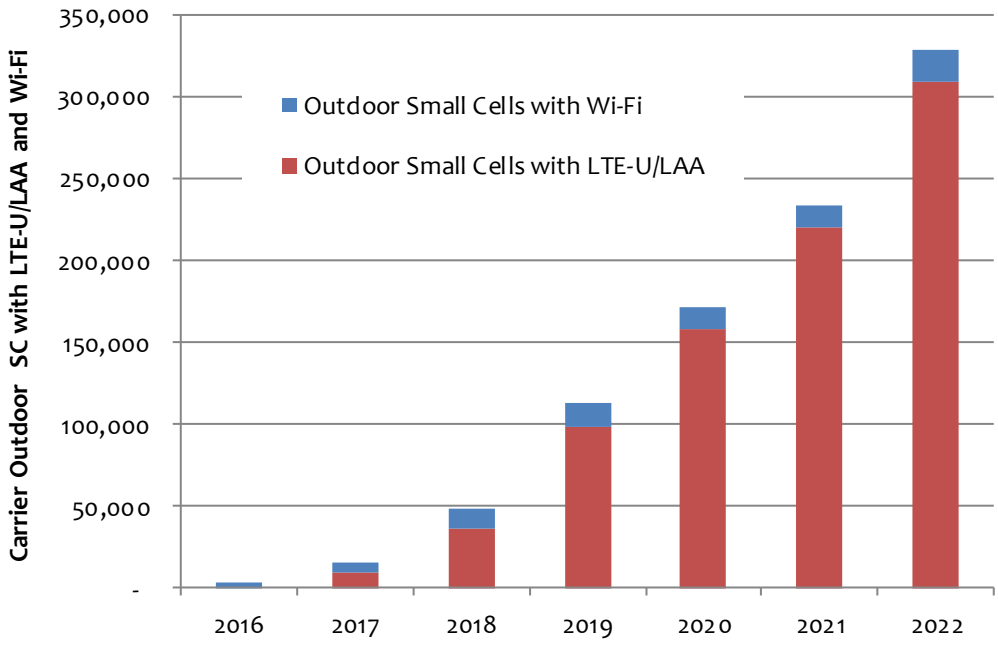
With many outdoor units supporting dual band carriers, Mobile Experts predicts the average number of bands per Carrier Outdoor unit to increase over time from 2 to 3 by 2022. With some units supporting multiple RF modules that can be customized for licensed LTE (FDD or TDD), unlicensed Wi-Fi and LAA, operators can aggregate multiple carriers to increase peak data rates and throughput capacity.



Source: Mobile Experts

Chart 46: Avg. # of Bands per Carrier Outdoor Small Cell Unit, 2016-2022

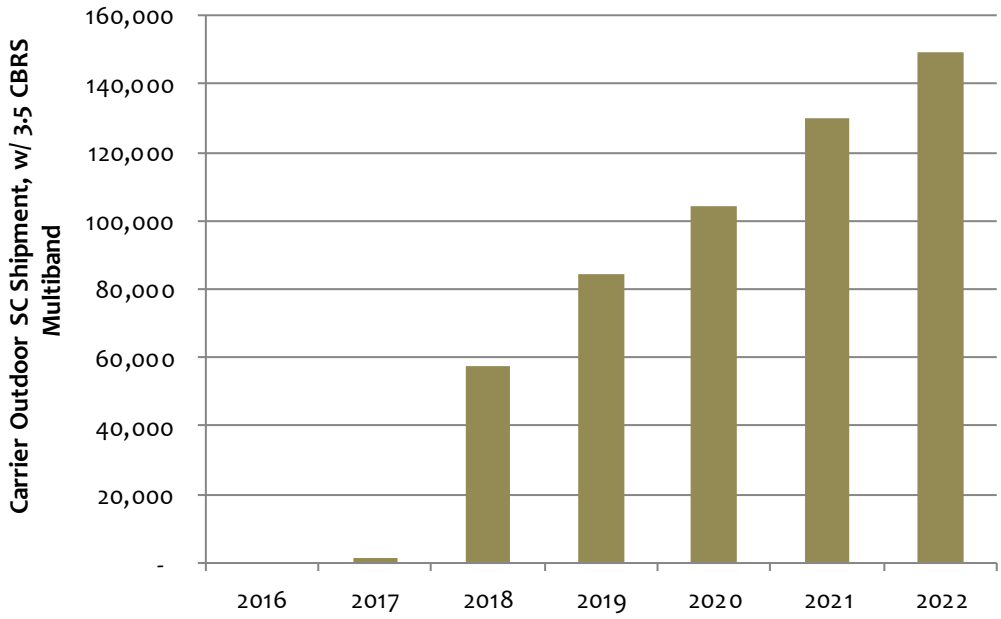
With more seamless network service integration with LTE-U/LAA over the 5 GHz unlicensed spectrum band, Mobile Experts predicts a high attach rate of LTE-U/LAA support for carrier outdoor units versus indoor ones as operators have a better control of where and how the 5 GHz unlicensed spectrum will be leveraged with LTE-U/LAA in the outdoor applications. Since most of Wi-Fi usage indoors is confined to inside of homes and commercial buildings, outdoor use of 5 GHz is expected to yield a 'cleaner' use of the 5 GHz unlicensed band with relatively high power small cells. (higher than 50-100mW consumer-grade Wi-Fi units). Carrier Outdoor small cells are less likely to include Wi-Fi as it is not enough to provide carrier-grade service, and the spacing between cells is very different for LTE and Wi-Fi. With LTE-U/LAA, Wi-Fi use by mobile operators is becoming less relevant.



Source: Mobile Experts

Chart 47: Carrier Outdoor Small Cell Forecast, with LTE-U/LAA and Wi-Fi, 2016-2022

Mobile operator plans for the 3.5 GHz CBRS are still in the early stages. Mobile Experts predicts the attach rate of 3.5 GHz CBRS multiband support to reach about 150K units by 2022. With multiple spectrum options at their disposal including AWS-3, WCS and 5 GHz unlicensed with LTE-U/LAA, it appears that the mobile operators in the USA have multiple ways to achieve wireless capacity expansion. As we observe Apple's support of this band, Mobile Experts will reassess our confidence level of our forecast and adjust accordingly in upcoming forecast updates.

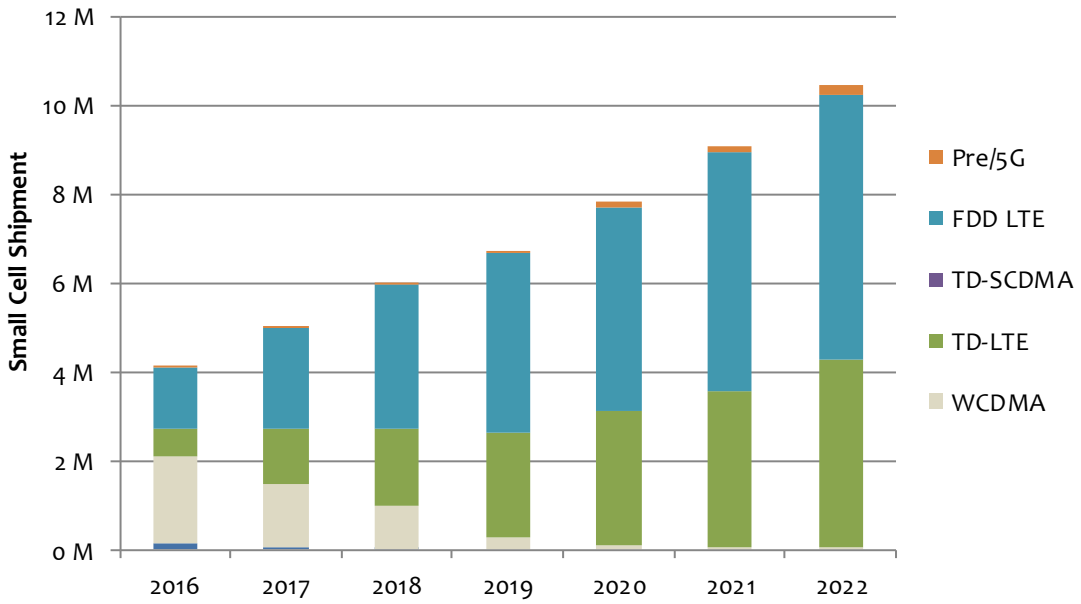


Source: Mobile Experts

Chart 48: Carrier Outdoor Small Cell Forecast, with 3.5 GHz CBRS Multiband, 2016-2022

Forecast by Air Interface Technology

The small cell share breakdown by air interface technology shows a rapid shift from 3G WCDMA to LTE. This shift reflects a transition from residential-grade small cells to carrier-grade units supporting advanced LTE features such as carrier aggregation and high order antenna configurations to achieve greater spectral efficiency. The carrier indoor and outdoor small cell market has quickly transitioned to LTE, and Mobile Experts predicts pre-standard 5G small cells to be deployed in Korea and the USA during 2017.

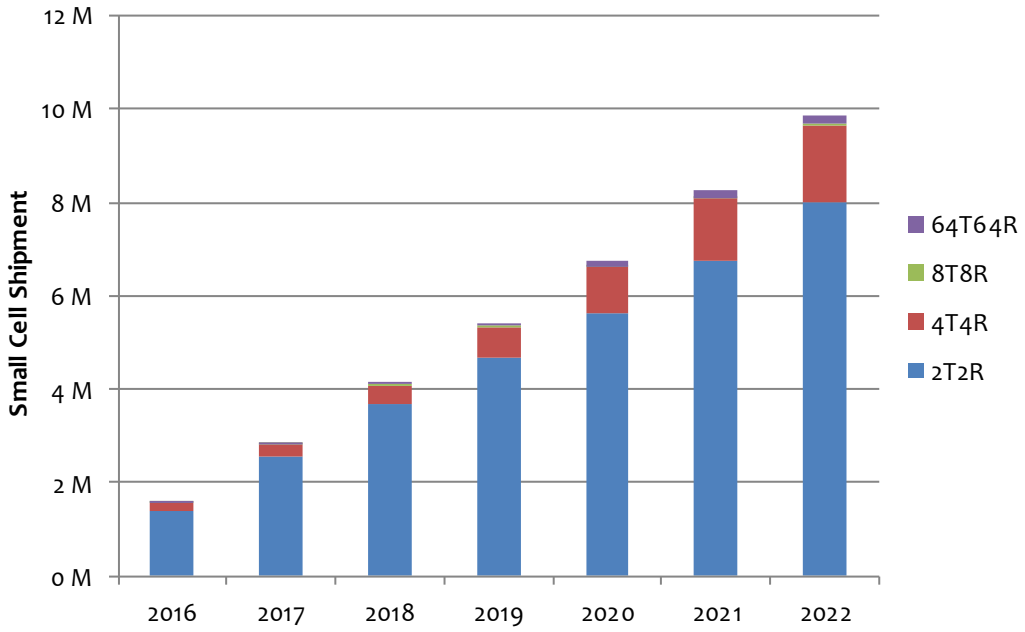


Source: Mobile Experts

Chart 49: Small Cell Shipments, by Technology, 2016-2022

Forecast by Antenna Configuration

As the small cell market shifts away from residential femtocells to high-capacity carrier units encompassing higher LTE features like carrier aggregation, multiband carrier support, the small cell units will increasingly adopt higher order antenna configurations from 2Tx / 2Rx to 4Tx / 4Rx and eventually to 64Tx / 64Rx antenna configurations to leverage massive MIMO features to achieve higher order spectral efficiency as operators leverage more spectrum bands and carriers across licensed, unlicensed and shared spectrum bands.

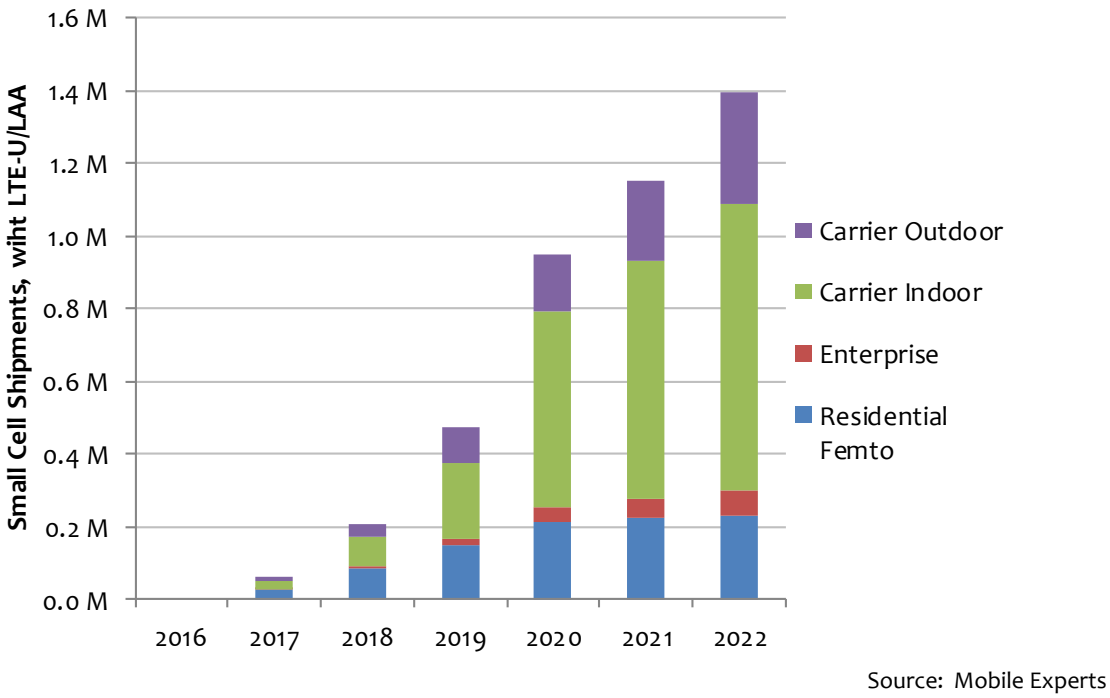


Source: Mobile Experts

Chart 50: Small Cell Shipment Share, by Antenna Configuration, 2016-2022

Forecast for LTE-U/LAA Radios in Small Cells

Carrier aggregation of licensed and unlicensed bands through LTE-U and LAA is expected to provide additional capacity relief for mobile operators. With FCC approval of LTE-U small cell units, Mobile Experts predicts Verizon and T-Mobile USA will selectively deploy this technology in indoor and outdoor applications to increase network capacity. With cross-industry rancor around 'LTE/Wi-Fi coexistence' debate, Mobile Experts predicts modest deployment of LTE-U/LAA in the carrier indoor context as mobile operators will be strategic in placement of LTE-U/LAA radios to avoid high-contention areas such as consumer homes. With a gradual ramp at second half of 2017, we expect the LTE-U/LAA radios to jump past the 1 million mark in 2021.

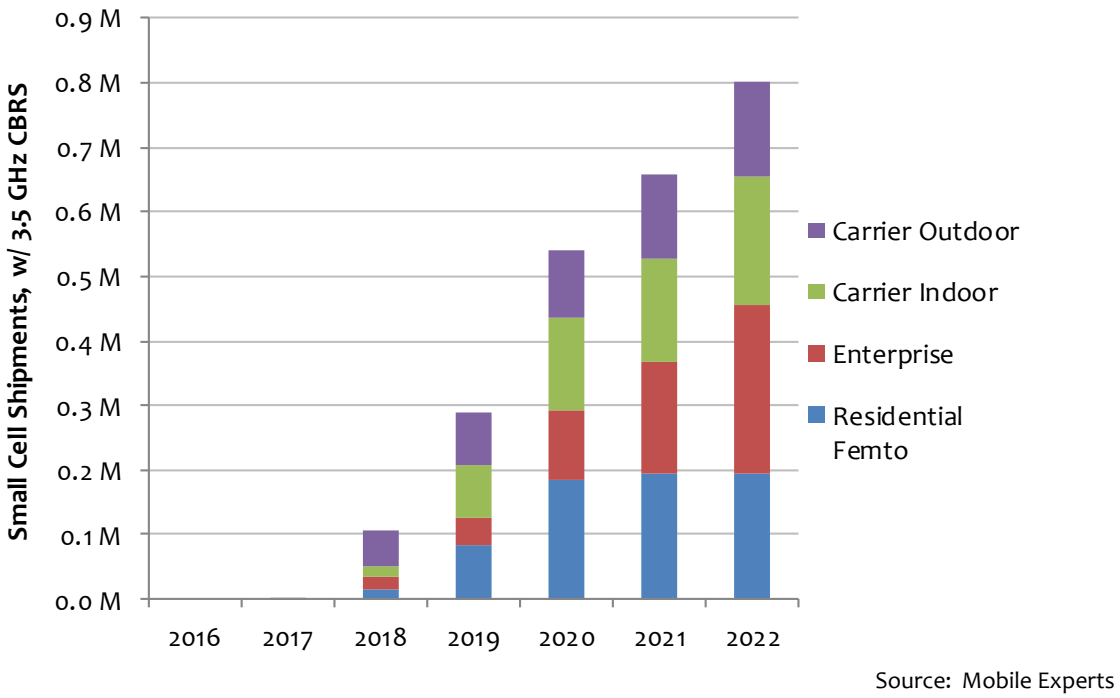


Source: Mobile Experts

Chart 51: Small Cell Shipment, with LTE-U/LAA, 2016-2022

Forecast for 3.5 GHz CBRS Radios in Small Cells

The 3.5 GHz CBRS ecosystem is still in early stages and mobile operator and device ecosystem is largely dependent on whether Apple devices will support this particular band/technology. Mobile Experts projects that we will see Android device support of this band in 2017. Whether Apple devices will support this band is highly confidential. We are currently projecting a modest uptake of the CBRS ecosystem starting in 2018. If cable operators jump into wireless market with serious intent and investments, the 3.5 GHz adoption in small cells will quickly ramp up beyond our current forecast.

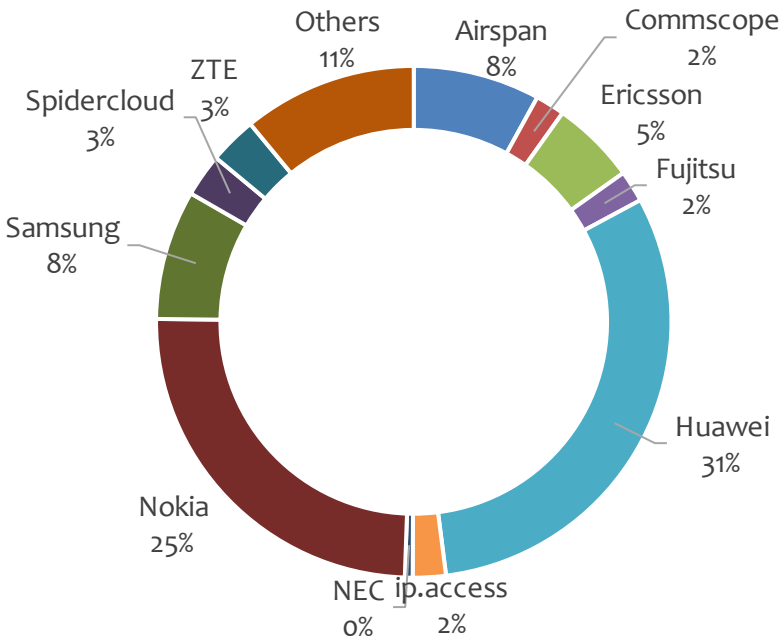


Source: Mobile Experts

Chart 52: Small Cell Shipment, with 3.5 GHz CBRS Radio, 2016-2022

8 MARKET SHARES

The small cell market is maturing. In 2016, we saw major incumbent infrastructure players extending their macro footprint and customer account relationships to extend their carrier product portfolio deep into Tier 1 mobile networks. Meanwhile, select enterprise-focused small cell vendors, who now have years of experience working with Tier 1 operators through the product approval process, have captured niche market segments and are looking to expand their footprint. Overall, the market is expanding for those who have established themselves in the market. These existing small cell market footprints may open up market opportunities as operators exploring unlicensed and 5G network architectures. Demand by vertical industry will fuel the growth.



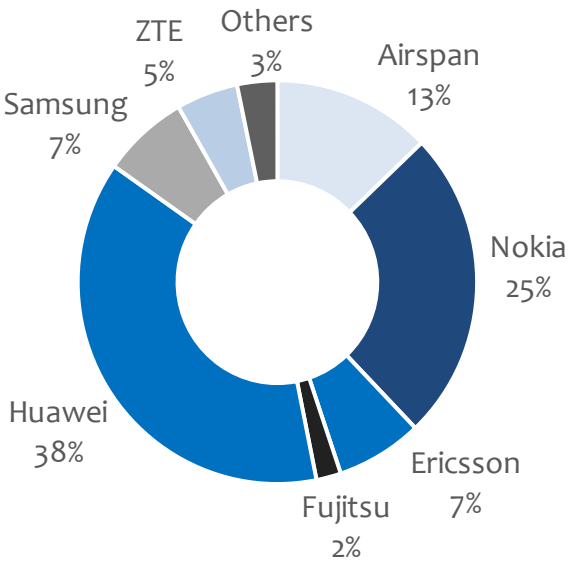
Source: Mobile Experts

Chart 53: Market Share by Revenue for Small Cells, 2016

Market Shares for Carrier Outdoor

Every major infrastructure OEM vendor has an outdoor small cell offering. In general, these tier 1 OEMs have market advantages in extending their macro footprint to provide 'macro parity' network management control and operational familiarity to carrier customers. For example, Huawei has been successful in leveraging its broad macro network footprints across China and APAC to sell through its LampSite small cell product. Nokia likewise has been quite successful in leveraging its 'macro parity' features of its small cell offering to meet specific market requirements. Airspan has defied a general industry norm and has established a foothold in the Carrier Outdoor market with its

strategic supplier relationship in Reliance Jio's LTE network rollout. Mobile Experts predicts Airspan will extend its market footprint also in North America in 2017.

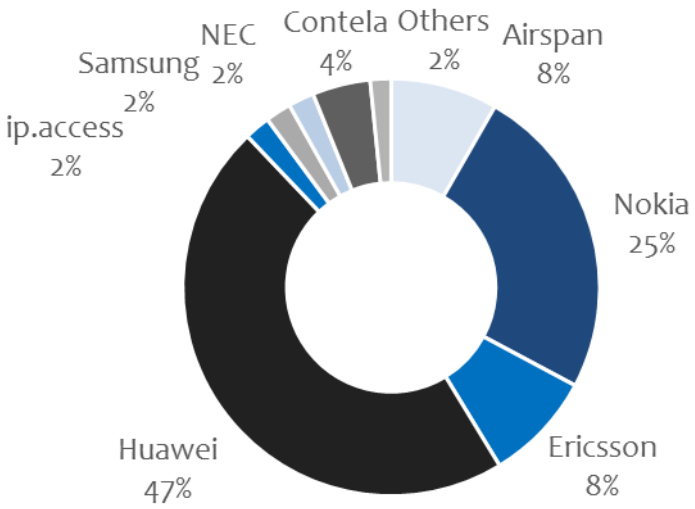


Source: Mobile Experts

Chart 54: Market Share for Carrier Outdoor Small Cells, 2016

Market Shares for Carrier Indoors

With almost doubling of its LampSite unit shipments in 2016, Huawei leads the Carrier Indoor segment. While Nokia also experienced growth in its small cell business, its primary focus has been in the outdoor segment. With robust demand coming from many markets, Mobile Experts predicts a continued market dominance from these two players.

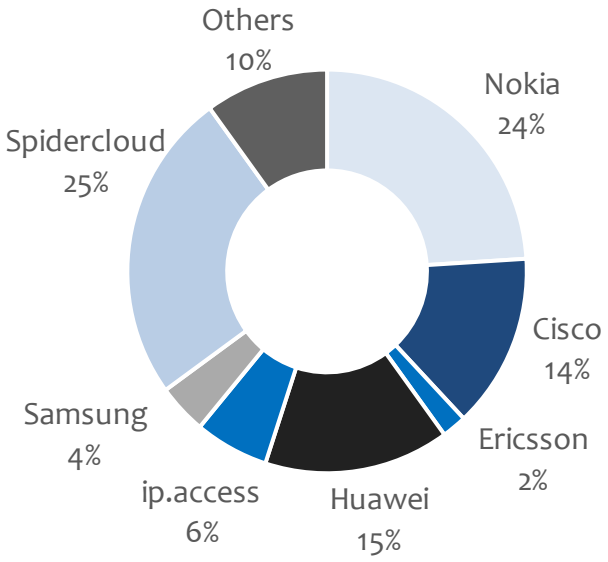


Source: Mobile Experts

Chart 55: Market Share for Carrier Indoor, 2016

Market Shares for Enterprise Small Cells

The enterprise segment is differentiated from the carrier indoor segment as enterprises have different priorities and requirements. However, carriers demand the same rigor in their approval process as they don't want any enterprise small cells to affect their macro network performance. In an odd way, success in this market segment requires OEM vendors to satisfy both the operators and enterprises. It is a challenging segment to succeed in, but some notable players have found market traction with tier 1 operators and certain enterprise channels. The major OEMs will also have a share of this market, but only for those vertical segments where 'macro parity' is essential.

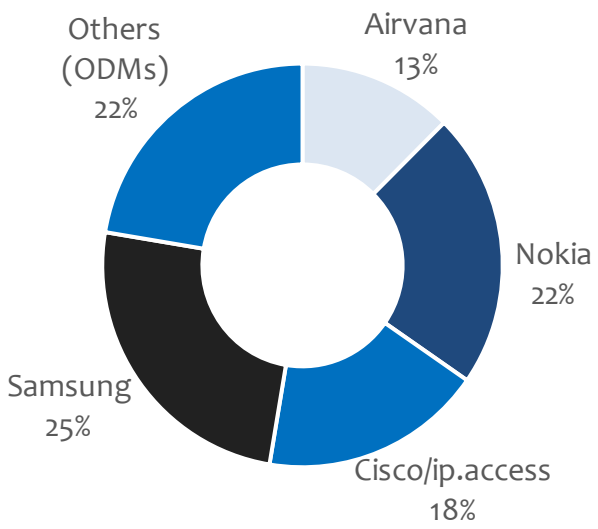


Source: Mobile Experts

Chart 56: Market Share for Enterprise Small Cells, 2016

Market Shares for Residential Femtocells

The residential femtocell market is a low-margin, high-volume segment, and Mobile Experts has seen several companies drop out. It is hard for any OEM vendor to solely focus on this segment for a sustainable business. Many of the leaders in this segment have other business lines to either support this effort, or being in this segment offers opportunities to pursue other higher-margin segments such as Carrier Outdoor and Indoor segments. Nokia and Samsung have long-standing carrier relationships with Tier 1 operators in North America to provide 3G/LTE femtocells, and Mobile Experts expects the trend to continue.



Source: Mobile Experts

Chart 57: Market Share for Residential Femtocells, 2016

9 COMPANY PROFILES

ACCELLERAN:

Accelleran is a small cell OEM start up based out of Belgium focusing efforts to produce LTE TDD small cells, targeting both licensed bands and shared 3.5GHz CBRS band for the US. At the MWC 2017, the company released its CBRS small cell based on Cavium SoC. The company has a few trials ongoing with cable and OTT operators in the US to pursue potential market opportunities leveraging CBRS. www.accelleran.com

AIRHOP:

AirHop Communications is a San Diego based company providing SON solutions for dynamic resource optimization and network management of heterogeneous networks. Founded in 2007, the company's SON solutions have been incorporated in several small cell deployments. www.airhopcomm.com

AIRSPAN:

Airspan Networks has developed a line of LTE small cells, including indoor enterprise units and outdoor units with integrated wireless backhaul. The company introduced LTE Relay system to boost network efficiency at cell edge. The company has deployed tens of thousands of small cells in India, as well as successful relationships with Softbank in Japan and with Sprint in the US. With successful small cell deployments, the company has tripled its employee base to pursue growing opportunities in North America, APAC and MEA. www.airspan.com.

ALTIOSTAR:

Altiostar has developed a split-baseband LTE RAN product line, which they are targeting at macro and small cell deployments. The company has set up a proprietary baseband partition in which the scheduler sits in the radio head, allowing higher latency in the transport and much lower bandwidth for lower transport cost. The company has announced its virtualized RAN solution and is conducting lab trials with few tier-one operators, including SK Telecom. The company recently announced a couple of partnerships with DAS vendors to apply its virtualized RAN solution to reduce fronthaul bandwidth requirement in DAS system deployments to support higher capacity requirements of LTE and upcoming 5G. www.altiostar.com

ARGELA:

Argela has close connections with Turkish mobile operators. As a part of Turk Telekom Group, Argela has a more direct route to market than other femtocell suppliers. The company recently demonstrated its ProgRAN solution that encompasses the programmable RAN solution based on the NFV/SDN principles. The platform was based on Cavium's baseband processor. www.argela.com

BAICELLS:

Founded in 2014, Baicells is a privately-held company based in Beijing, China. The company's product solutions range from indoor and outdoor small cells, CPEs, and antennas. With a new sales office in the US, the company is expanding into unlicensed and shared spectrum opportunities with cable operators and neutral host providers. The company announced its 'NeutralCell' small cell product at MWC 2017 leveraging 3.5 GHz CBRS. www.baicells.com

BENETEL:

Based in Dublin, Ireland, Benetel is a system design house focusing on small cell design and development. The company has a portfolio of baseband and RF modules and works with leading OEMs for custom design and development projects. The company's new design center opening in Poland may portend small cell market growth and market requirements for low-cost development and fast time-to-market production. www.benetel.com

BROADCOM:

Broadcom has grown their presence in small cells over the past few years, with very low power consumption in the PHY processing for a multimode small cell, as well as growing market share in the residential femtocell segment. The company had jumped ahead of competition in the enterprise small-cell segment with major wins at Cisco/SpiderCloud and early design wins for LTE small cells at KT, SK Telecom, and others. Their design touting low power consumption and a mature stack had been a key differentiator. After the Avago merger, the company has decided to exit the small cell SoC market. While the company continues to ship small cell SoC for existing commitments, Mobile Experts expect the production to stop in 2017. www.broadcom.com

CAVIUM:

As an established chipset supplier in Layers 4-7 for 3G core networks, Cavium started in a difficult position, but has emerged as a strong contender for Layers 1-7 by combining up to 48 processor cores and 2.5 GHz clock speeds in some very high performance SoCs. The key to the Cavium approach is to build in enough horsepower and memory that data flows through accelerators and processors without copying to memory, for an efficient solution. Cavium penetrated the early market in Korea with large volume shipments of carrier-grade small cell SoCs, but more recently has been focused on an innovative strategy for virtualization, to support CRAN in split-baseband product configurations. With Broadcom's exit from the small cell SoC market, the company has gained few additional customers and design wins. The company continues to invest in LTE baseband market as this effort can largely leverage the company's main investment in processor technology. www.cavium.com

CISCO:

Cisco's global footprint and channel sale partnerships especially in enterprise IT segment bolds well for its small cell solutions. Cisco has been working to arrange the business conditions for mobile operators and enterprises to support the upgrade from Wi-Fi to licensed/unlicensed operation. Endorsements from several tier-one mobile operators including Vodafone and EE have validated the Cisco enterprise approach. Cisco's strategic partnerships with SpiderCloud for enterprise small cell segment and also with the larger Ericsson partnership bolds well for its wider aspiration to increase share in the service provider segment, and small cell is expected to be a meaningful part of its offering to service providers. Cisco's "direct-to-enterprise" small cell strategy appears to have changed recently, as it plans to open its clip-on interface to small cell partners instead. Cisco's wireless strategy is still largely planted in Wi-Fi and IEEE 802.11 roadmap. www.cisco.com

CLEARSKY TECHNOLOGIES:

This Florida-based company provides hosted infrastructure and services to tier-two and tier-three mobile operators, primarily in the US. The company has recently announced its contract with GCI, a leading mobile operator in Alaska, to provide a complete small cell as service solution offering. www.csky.com

CLOUDBERRY MOBILE:

A Norwegian start-up promoting its managed small cells a service offering based on Cisco solution. The company has trialed few small cell network deployments in Sweden and Norway to promote its solution offering. In Norway, the company acquired 2.6GHz spectrum and planned to build and operate small cell networks on

behalf of operator customers in order to avoid leasing spectrum from mobile operator customers. www.cloudberrymobile.com

COMBA TELECOM:

Comba holds a strong position in supporting coverage solutions in China, as well as a few South Asian and Latin American markets. The company supplies a wide range of repeaters, DAS radio heads, TMAs, residential and indoor small cells, and other coverage related products. Comba has been highlighted recently as the first supplier of a "nanocell" for TD-LTE trials for China Mobile. www.comba-telecom.com

COMMSCOPE:

Commscope is a global leader in fiber connectivity and DAS systems whose IPR and product portfolios in in-building wireless space were expanded with acquisitions of TE Connectivity and Airvana. With the Airvana acquisition in 2015, Commscope has formally introduced a small cell product based on Airvana's OneCell. The OneCell concept combines aspects of small cells, DAS, and Cloud RAN to create a flexible in-building solution that can dynamically allocate capacity throughout a building, while avoiding some of the high cost items associated with DAS, and providing CRAN features such as CoMP and eICIC. Commscope's LTE/Wi-Fi small cell has been adopted by Sprint for indoor deployment. www.commscope.com

CONTELA:

Contela provides femtocells and related gateways for the Japanese and Korean markets, and has ramped to significant volume with more than 80,000 LTE small cells for SK Telecom. The company has been able to successfully penetrate at least two major customers outside of the Korean market, with significant shipments during 2015. www.contela.com.kr

CROWN CASTLE:

A traditional wireless tower company that is taking a more active role in the small cells infrastructure business. The company has made several fiber acquisitions in the US to bolster its small cells business by offering both backhaul transport (primarily dark fiber) and site leases for mobile operator customers to deploy small cells or outdoor DAS remote radio heads in key markets. The company's wireless infrastructure consists of 40,000 towers and 17,000 route miles of fiber. As of 2016, the company reports that its small cell infrastructure business now make up about 10% of its total business. www.crowncastle.com

CS CORPORATION:

CS sells repeaters in the Korean market and worked closely with SKT in the 2012-2013 timeframe to implement a customized stack and a small cell hardware solution. The company shipped significant volumes of LTE small cells to SK Telecom in 2012, but has not reached beyond this one opportunity in small cells. The company lists mobile communication as one of its wide range of businesses including digital broadcast, battery systems, and government electronics. www.cs-holdings.com

ERICSSON AB:

Ericsson showed up late to the small cell party, but they quickly took a leadership position in high-end small cells. The RBS6402 product incorporates 10 frequency bands with up to four running simultaneously, as well as integrated dual-band Wi-Fi. By offering a standard product with carrier aggregation and macro parity, Ericsson has established a gold standard in the high-end small cell market. Ericsson also offers the "Radio Dot" product as an approach for medium-sized enterprises. Ericsson's biggest move in the small cell market came with the news of its acquisition of BelAir Networks in March 2012. The combination of strong Carrier Wi-Fi and licensed-band small cell capability puts Ericsson in position to support converged small cells. With the recent Ericsson re-organization in March 2017, and ongoing Cisco partnership, it remains to be seen whether there will be a focused organizational business unit dedicated to small cell products (similar to Huawei's). www.ericsson.com

EXTENET SYSTEMS:

Extenet Systems is a privately-held wireless infrastructure provider of distributed networks. As a part of broader Digital Bridge holdings, the company designs, owns, and operates neutral-host networks leveraging multiple technologies including small cells, Wi-Fi, RRH, DAS, and other technologies on behalf of mobile operators and enterprise customers. The company recently partnered with Verizon to build out some of Verizon's small cell deployments in the San Francisco bay area. The company has ongoing projects with many of tier 1 operators in the United States. www.extenetsystems.com

FREESCALE SEMICONDUCTOR (NXP):

Freescale has a small market share position in residential femtocells, and has developed a product line of high-end SoCs to support major OEMs for small cells. The QorIQ product line includes a proprietary DSP core approach and an efficient interconnect fabric to enable LTE, 3G, and 2G sniffing simultaneously for high capacity applications. Beyond its traditional stronghold in macrocell chipset market,

particularly successful in the TD-LTE market in China, Freescale found success in the small cell segment with design win in the Airvana OneCell socket. The merger with NXP is not expected to have a significant impact on the Freescale small cell SoC product line as the two companies do not appear to have large overlaps. However, with the pending acquisition of NXP by Qualcomm, Freescale/NXP small cell SoC line will likely be absolved into Qualcomm's FSM product line. www.nxp.com

GOOGLE (ALPHABET):

With its core business of Internet search/advertising today, it may seem odd to put Google on our list of small cell company profiles. With its many wireless and telecom related activities, however, we have decided to put a placeholder here to signify the possibility of Google's influence in the small cells marketplace especially in light of its significant policy and ecosystem development efforts in the 3.5GHz CBRS space as well as other wireless/telecom initiatives already in progress, including Google Fiber, Google Fi, millimeter wave experimental trials, and not to mention its heavy influence in the device ecosystem with Android. Although Google Fiber initiative has largely scaled down, Google's experimental efforts in wireless seems to be continuing. Mobile Experts believes that Google's commercial aspiration in telecommunications market has largely scaled down as it focus on core Internet search and media businesses. www.google.com

HUAWEI TECHNOLOGIES:

Huawei is a shipment leader in non-residential small cells with success of its LampSite product line. The first two generations of LampSite, which can best be described as a low power RRH product with distributed RF, has been hugely popular in China and Southeast Asia. The product provides flexible indoor coverage/capacity solution with 'macro parity' features so that operators can reduce operational and management costs associated with running multi-layer networks. The company has focused its efforts on multi-band small cells for higher capacity carrier applications. With the next-generation LampSite, Huawei is targeting other regions including Europe where RAN sharing is more common. www.huawei.com

INNOWIRELESS (QUCELL):

Based in Korea, Innowireless provides network testing and optimization solutions. Most of their revenue is derived from testing/optimization services in North America. The company delivered tens of thousands of small cells to Korea Telecom for their LTE capacity upgrades during 2012 and 2013, acting as an ODM with a Cavium chipset and using software developed by third parties and by KT themselves. Recently, the company, under the "Qucell" brand, has been introducing both FD-LTE and TD-LTE

residential, indoor, and outdoor small cells based on Qualcomm chipset to KT, Fujitsu and others. www.qucell.com

INTEL:

Intel acquired Mindspeed in early 2014, combining the Intel strategy of network processing for Cloud RAN applications with the Mindspeed Transcede and Picochip femtocell products. Intel's open SoC platforms should lend themselves to split-baseband architectures, as well as low power small cell implementation. Beyond the past success of Mindspeed SoC at Contela and others, Parallel Wireless and ip.access are key OEM partners for Intel in introducing small cell solution leveraging Intel Transcede SoC solution. www.intel.com

IP.ACCESS:

Femtocell vendor ip.access has successfully penetrated the enterprise and rural/remote markets, as well as its longstanding residential success with AT&T Wireless and a few other mobile operators. With a recent investment from a private equity and several product introductions, including LTE access points covering more frequency bands to cover more markets, and the Viper platform to ease the enterprise small cell deployments, the company is looking to accelerate its growth. In a competitive marketplace with similar marketing messages around virtualized RAN with ease of deployments, it will likely come down to robust product features and tactical executions. www.ipaccess.com

JUNI:

With a research and development center in Korea, Juni has been developing LTE small cells based on Intel platform since 2009. It is focusing on CBRS market and has a trial ongoing in this space. www.juniglobal.com

NEC:

NEC has successfully deployed significant numbers of indoor and outdoor small cells for Softbank and other operators in Japan, but is not highly visible outside of Japan in radio hardware. NEC has partnerships with Netgear and Cisco/Ubiquisys, as well as core network integration relationships with Kineto, Tatara Systems, and Genband. NEC has successfully partnered with SpiderCloud to offer 3G/LTE and LTE-LAA solutions

for the enterprise segment.
http://www.nec.com/en/global/solutions/nsp/sc/index.html

NOKIA:

Nokia's primary business focuses on infrastructure for the macro layer, but the company has jumped into the small cell game as well. They have announced small cell relationships with T-Mobile and Avantel (Colombia), but in general Nokia has been more successful in outdoor deployment than with indoor small cells. Nokia has integrated a Ruckus Wi-Fi AP into their indoor small cell product line, to fill out the critical need for unlicensed operation. With the completion of its Alcatel-Lucent acquisition, Nokia has rationalized its small cell portfolio. It has kept the residentia/SOHO femtocell product line based on Qualcomm SoC. Its other indoor and outdoor small cells are based on its macro platform. With the common hardware and software stack, Nokia is able to scale up/down LTE features to address a wide range of small cell market segments from high-power outdoor units down to low power RRHs.
www.nokia.com

OCTASIC:

Octasic supplies DSP processors for small cells, and has a surprisingly high number of design wins for a small company. Octasic avoids competing with the big 'gorillas' in the industry by focusing on specialty markets including law enforcement, public safety, mining and oil exploration, and rural markets. www.octasic.com

OPENCELL:

OpenCell is a "small cells as a service" company based in the UK. It focuses on utilizing small cells to provide mobile coverage indoors, working closely with all major operators in the UK. www.opencell.co.uk

PARALLEL WIRELESS:

Since coming on the scene, Parallel Wireless has introduced several solution offerings targeted at different segments of the market. It has launched its distributed small cell architecture solution leveraging Intel SoC for small cells and HetNet Gateway to ease the deployment of LTE infrastructure. Its rural small cell deployment at EE, and HetNet Gateway solution for enterprise market has been well received in the market. More recently, it launched so-called "Band 14 in a box" to target public safety market, or more specifically FirstNet system in the US. The company has showcased many

interesting use cases of both high-power and low-power small cells in rural/remote applications in the UK, Australia, and the US. www.parallelwireless.com

PHLUIDO:

This San Diego-based start-up is working to define and develop a virtualized radio stack based on split-baseband RRH architecture to alleviate high fronthaul requirements and costs associated with managing virtualized RAN. The company's "radio-as-a-service" solution emphasizes the key value proposition of running virtualized radio access network via less costly fronthaul links. The company has trials in Europe and in North America to help minimize the link costs between virtualized baseband data center and remote radio heads. www.phluido.net

QUALCOMM:

Qualcomm was late to the femtocell chipset market, but it has become the dominant chipset supplier to the small cell market. Since its acquisition of DesignArt, Qualcomm has been continuously investing in this segment to expand beyond its stronghold in handset market to small cell infrastructure. More recently, it has expanded its OEM partnerships with SpiderCloud, Samsung, and many others to expand into licensed, unlicensed and shared spectrum bands. By leveraging much of the research and development from the handset side, the company has been able to expeditiously and in close coordination, to introduce complementary small cell infrastructure SoC platforms, including new generation of small cell SoC that supports LTE-U/LAA and CBRS. www.qualcomm.com

RUCKUS WIRELESS:

Ruckus Wireless uses adaptive antenna technology to deploy high-capacity, interference resistant Wi-Fi access points, and has focused on Wi-Fi offload for carriers such as PCW and KDDI. The company has partnered with Nokia for converged licensed/unlicensed small cells, and collaborated with Alcatel-Lucent on Licensed Wi-Fi Aggregation (LWA) which allows aggregation between LTE channels and Wi-Fi channels without forcing the LTE waveform into the Wi-Fi spectrum. Most recently, the company announced its OpenG technology initiative (based on 3.5 GHz CBRS) to provide cellular coverage and capacity indoors by leveraging shared spectrum for neutral host capable small cells. The company will find a new "home" after a series of merger announcements in the past year. Last year, Brocade, a networking company, acquired Ruckus as a part of its wireless strategy. A few months later, Broadcom announced its plan to acquire Brocade for Brocade's fiber channel storage area networking business. As a part of this complicated deal, Broadcom has agreed to sell Ruckus, and a part of Brocade's switching and routing business, to ARRIS. So, Ruckus

will now be part of ARRIS, soon after the Broadcom-Brocade merger closes. www.ruckuswireless.com

SAMSUNG:

Samsung has deployed millions of CDMA femtocells in North America, with both Sprint and Verizon Wireless using the Samsung "UbiCell" for initial deployments. Samsung also supplied picocells for WiMAX networks so they have easily converted to LTE small cell products, which have been selected by Sprint and a few other operators for ongoing LTE deployment. Most recently, Samsung has partnered with Qualcomm to support LTE-U/LAA capable femtocells. Samsung has been a key infrastructure supplier for Reliance Jio's LTE rollout, and looks to expand its infrastructure business in North America with learnings from the Jio network buildout. Samsung has a portfolio of residential, enterprise, and carrier grade small cells along with its macro product line used in the Jio rollout. www.samsung.com

SERCOMM:

Sercomm offers residential and enterprise small cells as well as Wi-Fi routers as a Taiwanese ODM. The company has taken the obvious step of integrating their Wi-Fi router and femtocell products together. Recently the company has focused on China and TD-LTE applications, and supplies TD-LTE, FDD-LTE, and dual mode TDSCDMA/TD-LTE small cells to that market. The company has also developed CBRS-capable small cell for the North American market. www.sercomm.com

SPIDERCLOUD WIRELESS:

SpiderCloud has been very successful converting their field trial and early deployments into major customer wins with Vodafone, Verizon, and America Movil. The company is seen as a major player in the enterprise segment with expanding product features and spectrum bands, including LTE-U/LAA, CBRS, MulteFire, etc. The company is focused on enterprise networks, using a centralized controller to coordinate both Wi-Fi and licensed/unlicensed/shared LTE radio nodes. The company has established a key partnership with Cisco, where they work together to outfit the Cisco Wi-Fi APs in the field with "plug-in" modules, and also where Cisco sells the SpiderCloud solution for enterprise opportunities. The company continuous to expand its strategic partnerships with leading infrastructure vendors and mobile operator partnerships for sell-through. www.spidercloud.com

TEXAS INSTRUMENTS:

TI's product lines support small cell deployment with integration of multicore baseband processors, as well as transceivers, ADCs and DACs, power over Ethernet, and other semiconductor functions. TI's strength in the KeyStone multi-core processor product line lies in small cells with relatively high capacity and functionality, running the same code as the macro base station in metrocells with multimode requirements. Of course, their existing relationships with Nokia and Ericsson come into play for "macro parity" small cells. TI's challenge in the high-end small cell market lies in balancing the relatively low volume of the high-end metrocell market against the R&D investment to migrate to the next process node. www.ti.com

Xilinx:

Xilinx supplies field-programmable logic chips to the telecom industry for applications in baseband and radio equipment. The company has long held a leading market share position in macrocell radio processing, and as the incumbent supplier they have an opportunity to participate in CPRI and split-baseband RRH units. www.xilinx.com

ZTE:

ZTE offers a complete line of small cell products, and should be considered a major contender for the "nanocell" tender in late 2015. The company has been commercially shipping femtocells to Starhub in Singapore since 2009. The company also recently touted Qcell (DRS architecture) solution win at China Telecom. The ZTE product line is based on software-defined radios based on Texas Instruments SoCs which have the horsepower to run macro-level software for ideal coordination in a multimode HetNet. http://wwwen.zte.com.cn/en/products/wireless/small_cell/201407/t20140716_425767.html

10 ACRONYMS

2G: Second Generation Cellular

3G: Third Generation Cellular

3GPP: Third Generation Partnership Project

4G: Fourth Generation Cellular

5G NR: 5G New Radio, global 5G air interface standard

5GTF: 5G Technology Forum, a Verizon-led industry forum for 28/39GHz fixed wireless access trial and deployment)

ADC: Analog-to-Digital Converter

ARPU: Average Revenue Per User

ASIC: Application Specific Integrated Circuit

BBU: Baseband Unit

BSC: Base Station Controller

BSOC: Base Station on a Chip

BTS: Base Transceiver Station

Bits/Hz/sec: Digital bits transmitted per Hertz of bandwidth per second

CA: Carrier Aggregation

CAT-5: Category 5 Ethernet cable

CBRS: Citizens Broadband Radio Service, a shared wireless broadband use of the 3550-3700 MHz (3.5GHz) band in the US

CDMA: Code Domain Multiple Access, a 2G radio interface

CLEC: Competitive Local Exchange Carrier

CoMP: Coordinated MultiPoint

CPRI: Common Public Radio Interface, a non-profit organization and interface format

CPU: Central Processing Unit

DAC: Digital-to-Analog Converter

DAS: Distributed Antenna System

dBm: Decibels of power relative to 1mW

DSL: Digital Subscriber Line

DRS: Distributed Radio System

DSP: Digital Signal Processing or Digital Signal Processor

eICIC: Enhanced Inter-Cell Interference Coordination

eNB: e Node B, or the radio access node for LTE

ESC: Environmental Sensing Capability, applicable for 3.5 GHz CBRS, detects incumbent use of the 3.5 GHz shared spectrum

FDD: Frequency Division Duplexed

FPGA: Field Programmable Gate Array

GAA: General Authorized Access, applicable for the 3.5GHz CBRS, the lowest priority access, similar to unlicensed spectrum use

GB: Gigabyte

Gbps/km2: Gigabits per second per square kilometer

GGSN: Gateway GPRS Support Node

GHz: Gigahertz

GSM: Global System for Mobile communications, a 2G radio interface

GW: Gateway (normally referring to a femto gateway)

HetNet: Heterogeneous Network

HNB: Home Node B (femtocell)

HSPA: High Speed Packet Access

HSPA+: A subsequent evolution of HSPA with higher throughput

HVAC: Heating, Ventilation and Air Conditioning

Hz: Hertz (cycles per second)

IC: Integrated Circuit

IDAS: Indoor Distributed Antenna System

IMS: IP Multimedia Subsystem

IP: Intellectual Property

I/Q: In-phase/Quadrature modulation, a typical digital format for communications signal

I-ub: Interface standard for base stations

I-uh: Interface standard for femtocell to serving gateway

Km: Kilometer

Low-E: low-emissivity glass that inhibits heat transfer. As a consequence, cellular signal does not penetrate well outside in

LTE: Long Term Evolution, a "4G" radio interface based on orthogonal frequency division multiplexed data

LTE-A: LTE Advanced, a higher bandwidth version of LTE

LTE-LAA: LTE-License Assisted Access, a 3GPP-compliant LTE-U technology

LTE-U: LTE-Unlicensed, a technology to run LTE waveform on 5GHz unlicensed spectrum band

OBSAI: Open Base Station Architecture Initiative, a non-profit organization and interface format

MAC: Media Access Control layer

MEA: Middle East and Africa

MHz: Megahertz

MIMO: Multiple Input, Multiple Output

MS: Mobile Station

mW: Milliwatt

OBSAI: Open Base Station Architecture Initiative

O-DAS: Outdoor Distributed Antenna System

OEM: Original Equipment Manufacturer

OFDM: Orthogonal Frequency Division Multiplexed

node B: A radio base station for WCDMA/HSPA

PAL: Priority Access License, applicable for the 3.5GHz CBRS

PB: Petabyte

PC: Personal Computer

PHY: Physical layer

QPSK: Quadrature Phase Shift Key

QAM: Quadrature Amplitude Modulation

QoS: Quality of Service

RAN: Radio Access Network

RF: Radio Frequency

RN: Relay Node

RNC: Radio Network Controller

RRH: Remote Radio Head

SAS: Spectrum Access System, to coordinate spectrum sharing in 3.5GHz CBRS

SCaaS: Small Cell as a Service

SGSN: Serving GPRS Support Node

SIP: Session Initiation Protocol

SNR: Signal-to-Noise Ratio

SoC: System on a Chip

TB: Terabyte

TD-LTE: Time Domain based Long Term Evolution

TD-SCDMA: Time Domain Synchronous Code Domain Multiple Access

TV: Television

UE: User Equipment

VoLTE: Voice over LTE

VoWiFi: Voice over Wi-Fi (sometimes referred to as "WiFi calling")

W: Watts

W-CDMA: Wideband Code Domain Multiple Access, a 3G radio interface

Wi-Fi: Wireless Fidelity (802.11 data communications)

WiMAX: Worldwide Interoperability for Microwave Access (a "4G" standard)

11 METHODOLOGY

To create estimates and forecasts for small cell shipments and revenues, Mobile Experts relied on direct input from more than 60 industry sources, with 30 mobile operators contributing to the overall analysis to give a detailed global view of the market. Mobile Experts built a "top down" forecast based on direct input from mobile operators and based on trends in end-user demand for mobile services. Then, Mobile Experts built a "bottom up" forecast through discussions with the supply chain. Roughly 40 suppliers, integrators, and OEMs participated in this phase of the survey. Mobile Experts also used financial disclosures from publicly traded companies to assemble a quantitative view of the equipment market.

This year, Mobile Experts has changed the model framework to track four categories: Residential / Enterprise / Carrier Indoor / Carrier Outdoor. The previous category of Hi Power units are tracked under the Carrier Outdoor, but is tracked separately as a sub-category. Portions of the Distributed Radio Systems such as Radio Dot and LampSite are tracked under the Carrier Indoor and Carrier Outdoor segments.

The independent market for Carrier Wi-Fi is not included in this analysis, but integration of Wi-Fi into licensed-band small cells is considered. In this report, we cover the integration of unlicensed and licensed-band connectivity, and shed light on the prospects for specific LAA/LWA/Wi-Fi/CBRS integration options.

Figures 19 through 22 give the detailed definitions for each category of equipment, for regions of the world, for multimode vs. single mode, for frequency band categorization, and for small cells as a service categorization.

Definitions	RF Power	Backhaul	Architecture
Macrocell	40W+ composite	Operator managed	Closely controlled cells
Traditional Microcell	5.1-29W composite	Operator managed	RNC or BSC architecture (2G/3G)
Traditional Picocell	300 mW to 5W composite	Operator managed	RNC or BSC architecture (2G/3G)
Low power CPRI RRH	up to 1W per antenna	CPRI, OBSAI, ORI to separate baseband unit	No baseband processing in radio unit
Low Power Split-Baseband RRH	up to 1W per antenna	Proprietary format	Split baseband with scheduler in RRH and other baseband functions centralized
Carrier Outdoor (High Power) Small Cell	5.1W/ant-40W composite	Operator managed	Coordinated with macro layer, LTE or 3G gateway; some fixed wireless application
Carrier Outdoor (Low Power) Small Cell	300 mW to 5W per ant.	Operator managed	Coordinated with macro layer, LTE or 3G gateway
Carrier Indoor Small Cell	<300 mW per antenna	Operator managed	Lightly Coordinated with macro layer, LTE or 3G gateway
Enterprise Small Cell	50 to 300 mW/antenna	Enterprise managed	Autonomous node (Gateway) or local controller.
Residential Femtocell	<50 mW/antenna	Consumer or SOHO managed	Autonomous node (Gateway)

Source: Mobile Experts

Figure 19. Detailed Definitions for each equipment category

North America:	USA and Canada
Latin America:	Mexico through South America, including Caribbean
Europe:	Western and Eastern Europe, including Russia
China:	China, including Tibet and Hong Kong
Asia Pacific:	India through Australia/Micronesia, excluding China
Middle East/Africa:	Pakistan and Turkey through Africa

Source: Mobile Experts

Figure 20. Detailed Definitions for regions

Multimode:	Capable of multiple simultaneous air interface standards (LTE, HSPA, GSM, etc.)
Adaptable:	Capable of one air interface standard at a time, but reprogrammable
Single-mode:	Capable of only one air interface standard

Source: Mobile Experts

Figure 21. Detailed Definitions for multimode/single mode

Multiband:	Capable of operating in multiple frequency bands, one at a time or simultaneously with separate baseband datastreams
Carrier Aggregation Units:	Units which operate in multiple bands with a single baseband datastream (inter-band CA)

Source: Mobile Experts

Figure 22. Detailed Definitions for multiband and carrier aggregation